A TREATISE

ON THE

Inspection of Concrete Construction

CONTAINING

Practical Hints for Concrete Inspectors, Superintendents, and Others Engaged in the Construction of Public and Private Works

BY

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"The Principles of Municipal Refuse Collection and Disposal"
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This Book is Affectionately Dedicated
To my Father
Jerome Boland Cochran, Esquire
Houston, Texas.

PREFACE

It has been the intention of the author of this book to set forth in detail all the principal points upon which information is likely to be wanted by an inspector on concrete construction. Many of the instructions given herein are applicable to building constructions and practically any type of reinforced concrete structures. The author is fully aware that many questions arise during a building operation that cannot be solved by reference to printed instructions, but he has endeavored to point out the essentials governing the construction of reinforced concrete structures. None of them may be new to some, some may be new to none, but it is hoped many will be of assistance to most. It is believed that everything said is based on sound practice and acknowledged authority, and that the young inspector will not be led astray, even if the old experienced inspector is taught little that he does not already know.

While the book consists of a series of rules and directions to be followed in inspecting concrete construction, with brief explanations of the reasons for each rule and of their importance, *it must be distinctly understood that the directions or suggestions set forth are not intended to run counter to, or be employed in opposition to, the directions and instructions given in the specifications under which the concrete work is being prosecuted.*

In the preparation of this book the endeavor has been to observe a logical order and a due proportion between different parts. Great care has been taken in classifying and arranging the matter. It will be helpful to the reader to notice that the book is divided successively into chapters, articles, sections and paragraphs. The constant aim has been to present the subject clearly and concisely. Every precaution has been taken to produce the work in a form for convenient use and ready reference. The table of contents shows the general scope of the book; and a very full index makes everything in the book easy of access. The preparation of this book has involved an immense amount of labor and the author hopes that its value to those engaged in the inspection, supervision and construction of works involving the use of concrete may be in some slight degree commensurate to the labor involved.

The general and specific instructions given in this book have been collected from a multitude of sources: from the engineering journals, from the transactions of the engineering societies and from the personal records of the author. Part of these instructions is taken from eight articles on the "Inspection of Concrete Work," prepared by the author for *Engineering and Contracting,* during January, February,

March and April, 1912. It is but fair to say that the great bulk of the matter contained in the book, though portions of it have appeared previously in other forms in the author's contributions to the technical press, was collected and worked up originally by the author. Where this has not been the case the original data have been added to and re-analyzed by the author.

Under the above circumstances it has been impracticable to give specific credit in the pages of the book to every source from which the author has drawn aid; instead, a list of the various text-books and technical dictionaries consulted is given at the end of the book. To the authors of these works the writer desires to give his thanks and acknowledge his indebtedness for information and suggestions. The author wishes here to especially acknowledge the help secured from the volumes of *Engineering and Contracting, Engineering News, Engineering Record* and from the *Trans. Am. Soc. C. E.* and the proceedings and papers of various other civil engineering societies and organizations of concrete workers. The work done by these journals and societies in gathering and publishing information on concrete construction is of great and enduring value and deserves full acknowledgment. The author also wishes here to acknowledge the help secured from the following works on concrete inspection:

Inspectors' Handbook of Reinforced Concrete, by Ballinger and Perrot. Eng. News Pub. Co., N. Y. City, 1909.

Inspection of the Materials and Workmanship Employed in Construction, by Austin T. Byrne. John Wiley & Sons, N. Y. City, 1911.

Instructions to Inspectors on Reinforced Concrete Construction and Concrete Data, by Geo. P. Carver. Payson Pub. Co., Beverly, Mass., 1907.

Practical Hints for Concrete Constructors, by Wm. J. Douglas. Eng. News Pub. Co., N. Y. City, 1907. Also published in Eng. News, vol. 56, page 643, Dec. 20, 1906.

Hints on the Design and Execution of Reinforced Concrete Works, by E. P. Goodrich. Eng. Rec., vol. 55, page 277, March 2, 1907.

Concrete Inspection.—A Manual of Information and Instructions for Inspectors of Concrete Work, by Charles S. Hill, C. E. The Myron C. Clark Pub. Co., Chicago, 1909.

A Handbook for Superintendents of Construction, Architects, Builders and Building Inspectors, by H. G. Richey. John Wiley & Sons, New York City, 1910.

Handbook of Instructions Regarding Materials and Workmanship for Superintendents and Inspectors of the Kahn System of Reinforced Concrete. Compiled by the Engineering Department of the Trussed Concrete Steel Co., Detroit, Mich., 1908. Also published in Eng. Rec., vol. 55, page 445, April 6, 1907.

Where it is possible to say so much, it is not easy to tell when to stop or when one has stopped short of saying all he should, and the author will not be surprised to find that he has erred at times in both respects. If those of his readers who discover such errors will tell him of them, the author will see that they are corrected. In fact, the author will be pleased to hear from any reader regarding any error, typograph-

ical or otherwise, found in this work, or any idea or suggestion that may be useful in a future edition; address the author, care of the publishers. By working together in this manner it will be possible to produce a work which will be of increasing influence toward good inspection in concrete construction, and this is the sole purpose of the author's work.

JEROME COCHRAN, C. E.

Detroit, Michigan, January, 1913.

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INTRODUCTION

There is quite a contrast between the quality of the average concrete, such as one sees mixed and placed by the average small contractor and many large contractors as well, and the concrete which is being made on some engineering works of large size, where such concrete as an engineer describes in his specifications is actually produced.

In making concrete on these works, good cement, good sand and good stone are assembled and a *measured* quantity of each is deposited in a large batch mixer and thoroughly mixed, with enough water to make a sloppy mass in which air bubbles will rise to the top on being puddled in the forms. The work goes on so rapidly that the form is filled to a considerable depth before settling begins, the soft concrete being put under a heavy hydrostatic pressure before this settling begins. This produces a far more dense concrete than was ever possible under the old practice when a dry mix for concrete and thorough ramming were universally specified by engineers.

Of course, it is well understood that a degree of perfection is possible in the inspection of the concrete work on these large structures, which is out of the question on any ordinary concrete job; but certainly the way average inspection is conducted leaves large possibilities for improvement.

For obvious reasons the inspection of concrete construction is generally the weak point in municipal and state engineering undertakings. It is often due to the employment of inferior inspectors, and frequently to the impossibility of even good inspection controlling certain contractors. The work is rarely bad, but it will not be as strong nor as lasting as a first-class job, and if such conditions are foreseen, and cannot be avoided, it is, perhaps, best to design the work stronger than would otherwise be required, as this seems to be the only practical method of meeting a recognized evil.

THE INSPECTION OF CONCRETE CONSTRUCTION

Concrete work of all kinds requires the most rigid inspection, as almost everything depends upon the quality of the materials and proper mixing and placing. The best design will come to nought unless it be carried out with the aid of careful and skillful workmanship and the use of good materials. Good construction can be assured only when the work is under the control of competent and conscientious inspectors. Reinforced concrete requires close, continuous, intelligent inspection.

Necessity of Inspection.—While the necessity of inspection depends to a certain extent upon the nature of the material and the production, it is always a question of just when and where, and to what extent it pays to inspect; but more careful inspection is certainly needed.

Take the average concrete placed in street or foundation work, for example, and, whatever the engineer's specifications may call for, this is what one commonly finds: For materials, whatever sand and stone or gravel the locality will furnish cheapest, with ashes—called, by courtesy, cinders—introduced as a variant. The ingredients are measured by counting the number of shovelfuls thrown into a heap; or, if Mike loses count, by stopping when the batch looks about right. Mixing is done by shoveling the pile over and over. The mix is shy of water, and has to be in order to permit shovel mixing; and even at that, more or less cement flows off on the street surface or seeps through the cracks in the mixing platform. To save it, more or less street dirt is scraped up and goes along into the mix.

By skillful use of mortar and trowel, concrete made in this way is given a fine surface and made to look like an excellent job, but the body of the concrete is of very variable composition and strength and the weak places yield under the influence of percolating water, ice formation, stresses and general wear and tear.

There is no building operation that can be more easily "skimped" without detection than the making of concrete, and the only way by which the engineer can be sure that his specifications have been strictly followed is by keeping a reliable representative constantly on the job.

The method of making and using concrete is very simple, but, owing to the fact that it is impossible to tell from an examination of the product the amount of cement that has been used, and the great temptation to the contractor is to use as little cement as possible, usually not more than one-half or two-thirds of the amount of cement specified is used (unless an inspector is kept on the job), and the mixing of the materials is also frequently very imperfectly done.

Unless thorough confidence can be placed in the honesty of the contractor to use the proportion of cement specified, it will be necessary to keep an inspector constantly on the ground to see that the full proportion of cement is used.

The inspection of a foundation wall cannot be too thorough, as there is nothing that causes an architect so much trouble as to have settlements in the foundations of his buildings.

Good inspection is necessary to insure proper construction and bracing where form work and placing of concrete are going on simultaneously.

It is very difficult to make the average small contractor or concrete workman take the pains to make high-class concrete; for he has found by experience that making it with any old materials any old way produces results which, so far as he can see, are good enough, while the refinements the inspector desires to obtain are looked upon as useless, theoretical, hair-splitting.

Object or Purpose of Inspection.—Inspection should be planned to accomplish at least expense the best results, which, according to Mr. E. A. James, in an article printed in the "Proceedings" of the Canadian Cement and Concrete Association, may be enumerated something as follows:*

1. To prevent loss or defects by accidents or delays.
2. To prevent loss of time and material on work already beyond repair.
3. To prevent the necessity of replacing defective work.
4. To prevent decrease in quality because of the demand for increase in quantity.
5. To point out imperfections in alignment, methods and material.
6. To record proper allowances for unavoidable extras.
7. To draw the attention of the superintendent to workmen who must be better instructed or trained.
8. To stimulate good will through fairness in fixing responsibilities.

Inspection organized to cover any one or all of these purposes will be similar in personality, varying only with the degree of perfection required. Before it can be determined just when and where it pays to inspect, the following conditions must be satisfied:

1. Responsibility must be fixed with certainty.
2. The inspection must not cause unnecessary friction.
3. The inspector must have to do with quality only, not design.
4. The responsibility for defective work must be placed upon the workman as well as upon the inspector.

The object of an inspector is to determine whether the contractor is living up to his specifications. The specifications should always be as complete as possible, and no contract should be let without them. There is nothing so unsatisfactory for both contractor and inspector as to try to accomplish an uncertainty in a satisfactory manner, and if they succeed in getting along well the conditions must be favorable.

Defective concrete work may be due to wrong specifications, poor material, defective measurement, defective mixing, or even unsuitable weather conditions. Therefore, instructions and specifications should be in writing. In other words, no contract should be signed without specifications, if anything is to be required and demanded, and neither party in signing should lose sight of what they are agreeing to do. Many contracts are signed with merely a glance at the specifications, and when the contractor, in the hurry of his work, is reminded by the inspector that some certain clause is not being complied with (of the existence of which, perhaps, he has never heard), it is sure to make trouble, especially if it is expensive to remedy. This at once makes unpleasant relations between the two, and only one party is to blame.

Troublesome Inspectors.—It is very unfortunate, both for owners and contractors, that there are inexperienced inspectors for reinforced concrete work. It too often happens that men of no theoretical

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or practical training in any branch of engineering, are deemed competent to decide upon the merits of work when they do not know the principles of its construction, and it is this class of inspectors, under certain circumstances, who are very annoying to the contractor and cause him most trouble.

A man's disposition determines, in a large measure, his success as an inspector. A naturally suspicious man makes his own life a burden, besides being a source of needless worry to all around him: while one free from suspicion and with even an ordinary amount of common sense and intelligence can get good work and make no trouble even if his technical knowledge is small.

If an inspector is determined to make things unpleasant he can always succeed in so doing, as his power for the time being is necessarily great; but unless his reasons are good he commands little consideration from the contractor, and soon becomes unpopular.

The author, although unwillingly, is in favor of a black list of troublesome inspectors to be circulated among concrete constructors, but feels that if the matter were to receive proper attention the most serious points that lie as stumbling blocks between inspector and contractor could be easily removed by a system of arbitration; that is, would place the blame where it was due, and thus avoid troubles, that, if not thickening, are growing none the less.

Rejection of Work.—A very unfortunate case is that of rejection of work by an inspector which the contractor feels is unjust, because the only appeal is to the inspector's superior, and in nearly every case he is sure to be sustained in his decision. If the inspector determines not to yield, the contractor in most cases must give up the fight. This is one of the most exasperating positions for him to be placed in, as he virtually has no redress. There should always be a clause inserted in specifications providing for arbitration, which would take care of a case like this. Otherwise, the only thing a contractor can do is to be very careful in signing a contract to ascertain who the inspector of the work is to be, and if the same is well known for giving trouble, throw up the contract unless another is substituted.

Scope of Inspection.—Inspection during construction should be made by competent inspectors employed by, and under the supervision of, the engineer, and should cover the following:

(a) The cement, the sand, the broken stone or gravel, the water.

(b) The correct construction and erection of the forms and supports.

(c) The sizes, shapes, and arrangement of the reinforcement.

(d) The proportioning, mixing, and placing of the concrete.

(e) The strength of the concrete by tests upon standard test pieces made on the work.

(f) The protection of the work against shocks, loads, the weather, etc.

(g) Whether the concrete is sufficiently hardened before the forms and supports are removed.

(h) Prevention of injury to any part of the structure by and after the removal of the forms and supports.

(i) Comparison of dimensions of all parts of the finished structure with the plans.

The inspection includes, in addition to the details already mentioned, the following:

(1) Great care in thoroughly joining new to previously laid and partially set concrete.

(2) The thorough cleaning out of forms before the pouring in of the concrete.

(3) The thorough and complete filling of all parts of the forms.

(4) The placing of all reinforcements in the exact position they should occupy.

Plans of Inspection.—There are many plans of inspection, any of which may get good results, and all of which may fail in securing good results. Inspection depends more on the inspector than upon the method. It may be made by central bureaus which retain men who are experts in their line of work who report to their bureaus, or to the engineer in charge of the work as may be arranged. Or it may be made by the engineer's own local staff or foreman, or by requiring such guarantees that inspection at the end of one or two-year periods will be all that is necessary. The plan of inspection to be adopted will necessarily depend on the character of the work being done.

Night Work.—If the work is to be done at night under artificial light it will be necessary to increase the staff of inspectors, for concrete that can be detected in the day time, by color, will not show lack of proper mixing of materials under artificial light. In fact, where high-class work is required, or in finishing surfaces, as a rule it is better not done at night at all.

During the progress of night work, it is necessary to be extremely careful that the work is carried on in exact accordance with the specifications. No night work should be permitted unless suitable arrangements are made for the lighting of the work. Night work should be carried on with as small a gang as will insure the placing of fresh concrete before that beneath it has set.

Cost of Inspection.—The cost of inspection is variable, being in some cases as low as one per cent of the total cost and as high as two and one-half per cent. As a usual thing two per cent should be allowed for inspection, and good inspection is cheap at that price. It is thought that 2½ per cent of the total cost of the work is a proper charge for inspection on first-class concrete work.

DUTIES OF THE INSPECTOR

Inspectors are placed on the work to keep the engineer informed as to the progress of the work and the manner in which it is being done. The duties and functions of an inspector are purely supervisory, and his decisions should be binding only in the absence of the engineer, and should be subject to his review. The inspector on the work is subject to removal at any time by the engineer.

Inspection work can be separated into two classes, but the duties

of each class are the same, the difference lying mainly in the fact that in the one case the inspector reports to the concern for whom the work is done and in the other he reports to the concern doing the work. In many cases the duties of the inspector are performed by those who have other duties assigned to them. This is, necessarily, the case upon small jobs, while on the large and important works there may be a number of inspectors among whom the different classes of work are divided.

It is necessary that the superintendent of construction, each inspector and the foreman of the various lines of building work should understand the position and authority of the inspector. The resident engineer and the superintendent must be familiar with the duties of the inspector.

Where possible, it is desirable that the duties of the inspector should be definitely outlined; it is, however, impossible to lay down a series of rules and regulations which will cover all possible contingencies, and common sense must be used in dealing with emergencies, in interpreting the rules and regulations governing the inspection of the work and materials and in interpreting the various clauses in the contract and specifications under which the work is being conducted.

The inspector represents the resident engineer or the superintendent of construction and is responsible for the correct detail performance of the work and of the duties assigned to him.

General Duties of the Inspector.—The details of the inspector's duty will vary with the character of the work. His general duties are summed up below. All these duties are dictated by common sense, but nevertheless daily violated, and it is therefore well to put them in the introduction.

1. The inspector should understand the plans and specifications under his charge.
2. He should carefully examine the samples of materials submitted by the contractor with his bid or during the progress of the work, as he will be justified in condemning material inferior to these samples.
3. He should see that all material used and work done is in conformity with the plans and specifications.
4. He should be familiar with the methods employed by the various craftsmen in executing their work.
5. He must be familiar with the characteristics of the materials with which he has to deal.
6. He should be a good judge of workmanship and know whether the finished work is what is required or expected.
7. He should take no person's word for anything but see for himself, and then be sure that he is not being deceived.
8. He should not issue instructions contrary to the plans and specifications.
9. He should not accept or approve any portion of the work, unless authorized to do so.
10. No information should be given regarding probable quantities

of work done or to be done, inquiries for such information being referred to the engineer or his superior.

11. He should point out the defects in construction and be able to locate the cause of the defect, and to suggest a remedy.

12. He should be able to detect defective work as soon as possible, so that the conditions under which the work was done may be fresh in the workman's mind, and the responsibility with certainty attached to him.

13. He should be sure that he is right before condemning a piece of work, and then take a firm stand.

14. He should be punctual and constantly on the work.

15. He should keep correct, careful and complete daily records of forces employed, material delivered, rate of progress, etc.

16. He should keep a small diary in which to jot down the principal events of the day.

17. He should keep records of work condemned, material rejected and reasons therefor.

18. He should see that no rejected material goes into the work.

19. He should be active and alert in seeing that the work progresses properly.

20. He should see that proper tests of the materials are made as the work goes on.

21. He should order the removal of incompetent workmen.

22. He should follow the instructions and wishes of his superior.

23. He should notify his superior of infractions of rules, poor work, errors or other difficulties.

24. He should protect the interest of his employer.

25. He should facilitate the contractor's work.

26. He should measure up the work done, if so requested.

27. He should order work stopped until the engineer can be communicated with, if, in his opinion, such action becomes necessary.

28. He should preserve marks set by the engineer until no longer needed.

29. He should assist the engineer or foreman in giving line and grade.

30. He should be tactful, determined and just.

31. He should secure as good and as rapid work as he can.

32. He should at all times be fair and reasonable with the contractor and must not be too exacting in particulars which do not materially affect the quality of the finished structure.

33. He should avoid arguments and disputes.

34. All disputes regarding the manner of doing the work and interpretations of the plans and specifications should be referred to the engineer in charge.

35. He should perform such other duties as the engineer may indicate or direct.

36. If the inspector is employed by the contractor, he should also be entrusted with the keeping of costs; a matter which will not be discussed in this book.

37. Last but not least, the inspector should not accept or receive

[illegible]

Familiarity with Plans and Specifications.—The [illegible] of the inspector [illegible] himself familiar with the plans and specifications [illegible] and with [illegible] as he may from time to time receive from the engineer—or the architect.

To perform his duty [illegible] he must make himself thoroughly acquainted with the requirements of the plans and specifications. A copy of [illegible] should always be in his possession in order that he may intelligently perform the duties intrusted to him.

Drawings for reinforced concrete buildings generally show dimensions, sizes, and amount of reinforcement, as well as the details of construction [illegible] only the architect's plans, [illegible] information that they give. In such cases, the general framing plans furnished by the reinforced concrete company or consulting engineers will have to be studied in order to learn the details regarding the distances from c. to c. of columns, beams, and girders as well as the amount of reinforcement required by each beam and girder and the slab construction. As a rule, the drawings are [illegible] to the specifications, and if the plans and specifications do not agree, the usual practice is to follow the specifications. It is best, however, if contradictions occur, to have an understanding at once with the architect or engineer controlling the work.

The inspector cannot become familiar with a complete set of plans, drawings, and specifications at once; it is only after going over them many times that he can fix the entire work thoroughly in his mind. An excellent plan, especially if the job is a large one, is to photograph the tracings and then mount the photographs on cardboard so that they can be carried in the pocket and studied at leisure.

Inspection of Materials.—The inspector is required to pass upon the quality of the materials delivered, and determine whether they meet the requirements of the specifications or not, rejecting all that are defective.

Inspection of Methods Used by the Contractor.—The right of the inspector to require special methods of manufacture or construction to be followed is not always clearly defined. Where possible an inspector should permit a contractor to employ those methods which previous use has demonstrated to be the proper practice, or to employ his own methods, so long as such methods cause no injury to the material or to the work and produce the required results. In fact, it is usually better, especially where a guarantee accompanies a piece of work, to allow the contractor to use the method he deems fit to accomplish the end sought than to insist on a method which, being no better, places the responsibility of the successful issue of the work upon the inspector, and hence upon his employer. But when a contractor deliberately attempts to use a method which is contrary to common practice in order to cheapen the work, or through ignorance,

it is the inspector's duty to order work stopped until the engineer can be communicated with, and the matter thus passed upon by his superior.

Essential Qualifications.—A satisfactory inspection cannot be made by an unskilled man, the duties of the position demanding one who has more than a superficial knowledge of the line of work and preferably a certain amount of engineering knowledge. The best inspectors are those who have some knowledge of engineering, enough at least to enable them to read and interpret a set of plans and specifications. However, many inspectors fulfilling this requirement are young and inexperienced to cope with the responsibilities of the position, and fall an easy victim to the flattery of an unscrupulous contractor.

While the inspector need not necessarily have a technical training, he should by all means have received sound elementary training, and should be endowed with some executive ability, and, especially, with practical common sense. In fact, the most essential qualification for the position is good, sound common sense coupled with an ability to keep the temper under strict control. Circumstances continually arise in this line of work which are aggravating and apt to lead to hasty speech. It is desirable that the inspector be able to keep his self-control in such emergencies.

One of the best qualifications for a successful inspector, after a thorough knowledge of the subject, is constant vigilance. To provide against slighting by careless and indifferent workmen, constant vigilance is absolutely necessary, especially in such parts of the work which are difficult of access or will be covered up. The general reputation of the contractor for doing honest work should not operate to lessen the vigilance of the inspector.

Preliminary Training.—The inspector should not be placed in charge of construction work until he has been thoroughly schooled in the duties of his position. He should be given the plans and specifications covering his work and should be required to study them carefully until he is thoroughly familiar with every detail as mentioned above. After he has acquired a thorough knowledge of the work to be done, he should be instructed as to quantities and qualities of materials to be used in the work. He should know when it is permissible to deviate from the strictly literal interpretation of the plans and specifications.

One week of good training in the engineer's or architect's office before inspectors are sent out on the work in the spring will save much time and trouble during a season's work. This preliminary training for an inspector not only fortifies him for his work, but also enables the engineer or architect to get a good line on the inspector as to his ability and general fitness for the position. In fact, the young and inexperienced inspector needs the advice and instructions of the engineer or architect. Training of the kind and in the manner suggested has produced good results in many cases. Public works officials will do well to keep a school of this kind, particularly where inspectors are chosen for the official and not by him.

Authority of Inspector.—The inspector is expressly forbidden to give any directions, either verbal or written, to the contractor except over the signature of the engineer in charge of the work. He will immediately report anything which may, in his judgment, be desirable to bring to the attention of the engineer. It is, however, desirable to avoid all friction and conflict of authority on the work, and in the interpretation of the instructions the inspector must use common sense.

The authority of an inspector should never be called in question. He should by all means be made fully to understand before he assumes the duties of his office just what authority he has, and just as fully made to understand that he must not abuse that authority. If he is in doubt as to any question arising over the work on which he is in charge, he should consult the engineer or architect and be positive as to his answer before he renders a decision. A decision should invariably be rendered through the inspector in charge, and when once given should be final. It is bad policy for the engineer, architect or chief inspector to issue orders or question any part of the work except through the inspector in charge unless called upon to do so by the inspector. It is always better to have the contractor or foreman in charge of the work understand that the inspector is in authority.

There should be at all times perfect confidence between the inspector in charge of the work and the engineer or architect. If this confidence is maintained there will seldom arise an occasion for the inspector's authority to be questioned.

If the inspector's work is not to be final (a condition of things which should never happen), he should know what he has a right to accept and what to reject.

Deviations Allowed by Inspector.—The inspector is not usually authorized to waive or alter in any respects any of the terms or requirements of the contract, to make additional requirements, to grant extensions or delays, or to waive forfeitures. In other words, the inspector has no authority to permit deviations from, or to relax any of the provisions of, the specifications without the written permission or instruction of the engineer or architect.

Few plans and specifications are drawn that will cover all conditions encountered during the progress of the construction of any improvement of consequence. Hence it is of great importance that the inspector in charge of any improvement should know when, how, and why deviations from the plans and specifications may be made.

Marking Rejected Material.—In marking rejected material the inspector must be careful to so place the marks that they cannot be readily erased or removed. As a distinguishing mark, the letter "R" or "C" may be used, meaning Rejected or Condemned.

Removal of Rejected Material.—It will not be sufficient only to mark the rejected material and rely upon its being removed by the contractor. The inspector must see that it is removed from the work and not again offered for use on any part of the work; otherwise, the chances are that part, if not all, of it will find its way into the work.

Delay in Inspection.—The inspector must not delay the contractor by failure to inspect materials or workmanship but should work with

reasonable promptness. In case of a piece of questionable work, reject it for the moment if other work is awaiting inspection, and decide finally at a more opportune time. The author has seen an inspector halt and deliberate for a whole day over one piece of work, while other urgent work was awaiting his inspection.

The inspector is expected to be on the work at all times while work is in progress, during the erection of forms, the placing of reinforcements, the mixing and placing of the concrete and the removal of the forms and the finishing of the work. His hours are the same as those of the contractor who is doing the work. Steadiness and close attention on the part of the inspector commands the respect of the contractor, and reflects credit on his employer.

Removal of Incompetent Workmen.—The inspector should keep close watch of each workman's manner of doing his work, and those who persist in doing defective work should be ordered removed.

Records.—The inspector will be required to keep a daily record of the progress of the work. He should provide himself with a substantial book, suitably ruled (or a book will be furnished the inspector), in which he should keep a record of the progress of the work. A very satisfactory way to keep such a record is to have a diary and jot down the principal events of the day; also the record of the work done on each day as given in his daily reports.

A record of the day's run may be simplified by dividing the plan of the building into panels corresponding to the bays of the building and numbering them consecutively. This key can be used when referring to a section of work, and is indispensable when the time comes for striking the forms, since then the panels that have obtained the required age can readily be picked out and the work of removing the forms of these only proceed, while the forms under the part not ready to pull can remain.

The following notes, together with such other special information as the engineer may direct, should be kept by the inspector: Date—Time of day or hour of each entry—Day or night work—Condition of the weather—Temperature—Location of the work with reference to the plan—Number and location of lights (if night work) and if properly lighted—Number of each class of men employed—Foreman—Type of mixing machines—Proportions of mixture—Size and number of batches mixed—Time required for mixing—Number of revolutions per batch—Arrival of material, its amount, character, and condition—Rejected material, its amount, kind, and character of the defects—Condition of the forms—Condition of steel reinforcement—Date of placing concrete—Number, time and location of test cubes taken—Date of removal of forms—Appearance of finished work—Means for the protection of the finished work—The progress made—Orders received and given—Accidents—such other information as will assist in making a concise and accurate record of the progress and cost of the whole work or any part of the work.

It is very important that records be kept of the actual cost of all work, where possible, in order to determine upon the proper price for the extra work. The various inspectors and foremen under the

[illegible] and lay [illegible] engineers should [illegible] contractor's [illegible] and [illegible] entire form.

Reports.—[illegible] render [illegible] weekly reports [illegible] of that period's work. This report is made up from the record of daily reports, and should give such [illegible] details, figures, and descriptions as will enable the engineer to judge of the progress of the work. Sometimes the inspector is required to fill in a daily report sheet, printed forms being furnished for this purpose, and these reports turned in at the close of the day. Clerical work is a difficult problem to most first-class inspectors, and therefore their reports should be simplified for them as much as possible by the use of printed forms.

The inspector should be made to understand fully the importance of these reports. Unless they are carefully and accurately kept their value is entirely lost. If the inspector is careful to report daily the quantities of material used and the amount of work completed, together with the labor required, the engineer, architect or chief inspector can very readily ascertain the progress of the work and render safe judgment as to its merits.

Facilitating the Contractor's Work.—It is not only the duty of the inspector to see that the contractor performs his work properly, but he should facilitate the contractor's work and render him every assistance in his power by so arranging his work as to inconvenience the contractor as little as possible. The inspector must be on hand at all times so that workmen can consult him about any questionable points as they arise, and in this way avoid a great deal of friction which might occur if they proceeded in the way that semed best to them.

To insure prompt execution of the work the inspector should pass upon it promptly and decidedly, and should know just what to give and take in case of a question on a minor point. An inspector who adopts a standard within the reach of mortal man, and sticks to it, has less trouble with the contractor than one who is changing constantly. The two arrive at a distinct understanding and each knows when he has passed the line.

The best results in any piece of construction work can be secured only when the engineers or architects and inspectors in charge endeavor to work in complete harmony with the contractor, and for their mutual good. The contractor who is treated kindly and humanely, who is given to understand that certain things must be carried out as specified while he is left to work out the details to his best advantage; such a contractor, if he be further assisted in every possible legitimate manner, soon realizes that the engineer, architect or inspector in charge means business, and he is then ever ready to listen to suggestions made by the latter.

The inspector, however, should in no case act as a foreman for the contractor. That is to say, he must not under any circumstances make

any agreement with the contractor for the furnishing of material, teams, or labor. He must not interfere with the management of the contractor's work.

Interpretation of Plans and Specifications.—The plans and specifications for each particular work must be the inspector's guide as to the character of the materials and workmanship required, and in case of any discrepancy between them or doubt as to the meaning of any of the clauses in the specifications, the matter must be submitted at once to the engineer or architect for interpretation. Under no circumstances should the inspector proceed in doubt and take chances on everything coming out satisfactory. As a rule, the drawings are subservient to the specifications, and if the plans and specifications do not agree, the usual practice is to follow the specifications. It is best, however, if contradictions occur, to have an understanding at once with the engineer or architect controlling the work.

Very often the inspectors appointed on public works are anxious to do good work. However, as a rule they are not familiar with engineers' plans and specifications, and they have only the knowledge of the average citizen relating to the materials and methods of construction. The conscientious inspector of this type is very likely to cling too closely to the literal interpretation of plans and specifications and this course on his part almost invariably involves him in difficulties with the contractor. The quality of the work executed under such conditions always is impaired.

Those readers who may be interested in the interpretation of plans, specifications, contracts, etc., are referred to an article by the author on "Interpretation of Documents Composing Engineering Contracts," in the *Cornell Civil Engineer*, Vol. 20, page 364, April, 1912.

Failure to Comply with Plans and Specifications.—On the failure of the contractor or any of his workmen to comply with the requirements of the plans and specifications, the inspector should notify him or his highest representative of the defective work and allow him a reasonable time in which to make it good, as it is not the inspector's duty to apply the remedy or to interfere with the workmen. If at the end of this time the rectification is not made, or if he refuses to comply with the notice, the inspector must at once report all violations of the plans, specifications or contract, or any departure from strictly first-class work to the engineer in writing with full particulars of the case, concise description of the defective work, character of the order given, and reasons advanced by the contractor for refusing to conform to the notice.

When the inspector has reported defects in material or workmanship to the contractor and engineer, or their representatives, he must content himself with awaiting the corrections through the proper officials, although it should be within his power to stop or reject the work until there is an opportunity for investigation, and to take upon himself these responsibilities he must have knowledge equal to that of the superintendent of the work.

Where it is known that the contractor is encouraging his men to skimp the work the inspector should lay his information before the

engineer, and at once vigorous measures should be taken to remove such contractor from the work, for he will not do good work, no matter how thorough or painstaking the inspection may be.

Complaints: How Made.—Before raising objections or making complaints, the inspector should be quite sure of his case in order to avoid arguments and disputes, and then in as few words as possible make the complaint known first to the contractor or his authorized representative, and afterwards to the engineer, if necessary. Be sure you are right before making a complaint, and then take a firm stand. Don't let the contractor deceive you into believing that the material or workmanship is first-class when it is not. The complaint should by all means be made promptly, for the longer it is put off the more difficult will be the rectification.

Arguments and Disputes.—The arguments and disputes most frequently occurring between inspectors and contractors and their representatives are due mainly to complaints of the former of nonperformance of the work in accordance with the requirements of the plans and specifications, and, on the part of the latter, complaints of too close refinement or exactness or undue severity. These complaints are to be expected and the inspector should at all times be fair and reasonable with the contractor. He must not be too exacting in particulars which do not materially affect the quality of the finished structure, but if it is an obvious violation of the plans and specifications, he must not let the contractor mince the truth in his explanations and excuses.

Adjustment of Disputes.—The inspector will find a very trying and unpleasant task in adjusting these disputes with the contractor, unless he be possessed of a large fund of amiability and common sense. The inspector who errs in his decisions or is irresolute in his position is more likely to have bad work thrust at him than one who can distinguish between a mere blemish and a real defect, and who thoroughly understands his position and can maintain it with firmness.

All disputes regarding the manner of doing the work and interpretations of the plans and specifications should be referred to the engineer, if the inspector is unable to cope with the situation.

Communications.—Where possible all communications of importance should be transmitted in writing, the inspector retaining a copy. Telegrams and telephone messages should be duly confirmed in writing.

Influencing the Action of Inspectors.—In many cities the payment of compensation, or the giving of gratuity, or the granting of valuable favors or such other means are often employed by contractors to unduly influence the action of inspectors and not infrequently the latter not only accept, but persistently demand, valuable considerations from the contractor. Such practices are recognized as wrong, and as presumptive of fraud and malpractice on the part both of the contractor and the inspector. There is absolutely no excuse why an inspector should place himself under obligations to any contractor.

Specific Duties of an Inspector on Reinforced Concrete.—In no

other kind of building construction is there so much need for inspection as in reinforced concrete. The best designs and materials are of no avail if the work is improperly done. For the inspection of reinforced concrete construction the utmost competency and thoroughness are absolutely essential. An inspector on such work should have a knowledge of the principles of reinforced concrete design. Such information may be obtained from almost any of the books now on the market pertaining to concrete or reinforced concrete and will not be repeated in this book.

A few points for an inspector to watch closely in reinforced concrete work might be mentioned, as follows:

1. There is the inspection of the cement in its manufacture, after delivery, and on the job to see that it is all of the same brand and in good condition—Inspection of the sand as to its cleanness and condition—Inspection of the broken stone as to its strength and size—Inspection of the mixture of the three materials mentioned—Inspection of the amount of water added to make the proper consistency—and Inspection of every batch of concrete to see that it is mixed in exactly the proportion specified. These constitute only a small part of what is required of an inspector on an important reinforced concrete construction.

2. There is the inspection of the forms and supports, the quality of the timber, the method of putting it together to meet the intention of the designing engineer, and with a view to its easy removal so as to be used again.

3. There is the inspection of the steel in the reinforcement, the method of making and shaping, and of assembling and connecting the reinforcement, and, finally, of placing and fastening it. The inspector should constantly keep in mind that reinforced concrete is a composite construction, that it is essential to have not only good concrete but to have a sufficient quantity of reinforcing steel, and whenever in doubt, it is always better to err on the side of safety and insert the reinforcement where common sense dictates, even though not called for by the drawings. A very little experience should teach an inspector where continuity bars are needed, even if they have been omitted from the drawings; and in case of such omission, if it should appear that continuity bars are needed, communicate with the engineer, but do not omit them from places where common sense would indicate they are required. Sometimes extra steel is needed where it is necessary to make a joint due to rain or some unavoidable accident.

4. The filling of the forms, the spading and tamping or puddling of the concrete around the reinforcement and against the forms and the joining of new work to old must be carefuly watched. An eye must be kept on the forms ahead of the concreting to see that they are cleaned free of shavings, sawdust, dirt, etc. The cleaning of the forms is an important item and must be well looked after by the inspector. While this is going on the inspector must watch the action of the forms and supports and the setting of the cambers, look out for leaks, and at the same time keep an eye on the contractor's men

to see that they do not run wheelbarrows or carts over the finished work, or carry heavy loads over the same.

5. It is the inspector's duty to see that the concrete is properly protected after being placed. The concrete surface must be kept moist by wet sawdust, sand or blankets during the summer and properly protected in winter from freezing.

6. It is also the inspector's duty to see that the forms remain undisturbed until the concrete is hardened sufficiently to enable the removal of the supports and braces keeping them in position.

ERECTION OF REINFORCED CONCRETE BUILDINGS

The process of erection of reinforced concrete buildings has some details in common with that of the erection of buildings of ordinary construction. In other details, however, the procedure is quite different. The following summary of the details pertaining to the erection of such structures is all that can be attempted in this introduction. Most of the details are discussed in the following articles in connection with concrete work in general.

For detailed discussions and illustrations of various reinforced concrete buildings to be used for different purposes, the reader is referred to the many books on this particular branch of construction.

Process of Erection.—The following are about the usual steps in about the order in which they are taken:

1. The preparation of the site of the building and the excavation.
2. The laying out of the foundations for walls, footings, etc.
3. The erection of the forms.
4. The placing of the steel reinforcement.
5. The proportioning and mixing of the concrete.
6. The placing and tamping or puddling of the concrete in the forms and around the reinforcement.
7. The removal of the forms and supports after the concrete has set.
8. The finishing of the concrete surfaces.
9. The finishing or laying of the floor and roof surfaces (wearing surfaces).
10. The testing of the completed building.

Details (3) to (7), inclusive, are successive steps in the process of erection, which are progressive. That is, for example, (5) and (6) may be going on for one story or floor, while (3) is going on in a story above, (7) in a story below and while (5) is going on all the time.

In the ensuing articles it is proposed to give the information that an inspector of reinforced concrete building construction should possess in regard to the erection of the skeleton framework.

FAILURES IN CONCRETE STRUCTURES

Failure in concrete or reinforced concrete structures may be divided into two classes: (1) Failures from unavoidable causes; and (2) Failures from preventable causes.

Failures from Unavoidable Causes.—Under this class will come earthquakes, explosives, lightning, fire, inundations, tempests; and the author knows of no material which, if properly designed, can resist any of the above so well as reinforced concrete.

Failures from Preventable Causes.—Failures in plain concrete structures may be classified as follows:

1. Failures due to the use of green and unseasoned cement as well as poor cement—Inferior grades of sand and stone—Badly mixed concrete or insufficient water to permit the concrete to attain its full strength.
2. Failure due to placing concrete during the winter months and allowing the material to become frozen before the concrete has attained its final set.
3. Failures due to the use of calcium chloride.
4. Failures due to the placing of concrete in very hot weather when the temperature of the water is around 90° to 100° F., the cement at the same time being improperly seasoned, with the result that the cement gets an initial set in the mixer and is thereby broken when placed in the work.

This analysis will show that a great number of the failures are due to mechanical incompetency.

From the past history of concrete there is good reason to believe that if Portland cement is properly manufactured, the proper kind of aggregates used and the work properly done, structures built of concrete will be reasonably permanent.

Concrete is one of the best and most reliable of building materials when mixed and put in place in a proper manner; where there have been failures in reinforced concrete buildings or other reinforced structures for that matter, it has generally been due to one or more of the following causes:

1. Too early removal of forms has been the cause of most of the deplorable accidents in reinforced concrete construction.
2. Errors in calculation or insufficient and poor reinforcement.
3. Insufficient or badly arranged forms and supports.
4. Mistakes in the construction of the columns.
5. Unsuitable aggregate or cement.
6. Poor mixing.
7. Bad workmanship or inefficient supervision.
8. Misplacing or omitting the reinforcement.

Any of the above causes or any of those stated for plain concrete failures may be responsible for a reinforced concrete structure being a failure, but there is absolutely no reason, if these matters are carefully attended to, why every structure should not be a complete success.

CAUTION

The engineer or his authorized representative, alone, have any authority to give directions in regard to the work. Any directions involving the slightest departure from the plans or specifications or from both must be given in writing. Particular care must be used to

follow this direction. No man upon the work is to be permitted to receive any orders whatsoever, except from those placed directly in authority over him.

Field inspection is much more important in the construction of reinforced concrete than in timber or steel construction, for in the latter only the connections are made in the field and defects in them are easily seen, while in the former the entire structure is fabricated in the field and defects are for the most part hidden.

Naturally the person most apt to be blamed for concrete failures is the contractor. He, it will be said, is the responsible party. With that view the author cannot wholly agree. The contractor should not be absolved from blame, but the engineer and the architect, who do not know the dangers, must equally share the responsibility. It is their business to know the necessary precautions and to insist that a competent concrete engineer or experienced inspector be put on the job, there to stay until the work is completed. It is high time that those be adjudged incompetent who fail to insist upon such supervision.

CHAPTER I

INSPECTION OF HYDRAULIC CEMENT

The purpose of this chapter is to supply practical information regarding the classification, storage, inspection and test requirements of hydraulic cements. Theoretical considerations of the materials and methods of manufacture of cement and of the chemical changes which take place in setting are to be found in several other books, and are not of great interest to an inspector on concrete construction. The space which they would take is devoted to much more intimate detailed information of methods of testing cement and of the significance of tests.

Art. 1.—Classification of Cements

Hydraulic cements, which are the kinds used in concrete construction, may be classified according to the method of manufacture, under three general headings: Portland cement, Natural cement, and Puzzolan or Slag cement. The relative importance of each cement is indicated by the order in which it is named.

PORTLAND CEMENT

The term *Portland cement* is commonly used to designate hydraulic cement formed by burning an artificial mixture of calcareous (containing lime) and argillaceous (containing clay) materials in proper proportions to the point where they begin to fuse or melt. The materials then combine chemically and form a hard clinker, which is ground to a very fine powder. The definition of Portland cement is often further limited by specifying that the finished product must contain not less than 1.7 times as much lime by weight as it does of those materials which give the lime its hydraulic properties, i. e., silica, alumina, and iron oxide together, and must contain no materials added after calcination, except small quantities of certain substances used to regulate the action or the time of setting. The mixture of calcareous and argillaceous materials generally consists of approximately 3 parts of lime carbonate to 1 part of silica, alumina and iron oxide. Portland cement is so named because of the resemblance which hardened mortar made of it bears to a stone found in the Isle of Portland, off the south coast of England.

Sand Cement.—Silica cement or sand cement is a patented article manufactured by grinding together silica or pure sand with Portland cement, by which process the original cementing material is made extremely fine and its capacity to cover surfaces of concrete aggregates is much increased. This mixture is usually so finely ground that about 95 per cent of it will pass through a sieve having 200 meshes to the linear inch, the 5 per cent of residuum being sand. In other words, all of the cement passes a No. 200 sieve. Sand cement made from equal weights of cement and sand approximates in tensile strength to the neat cement and the material is sold as cement. Proportions as lean as 1:6 have been made to compete with Natural cements. Sand cements are of comparatively little importance, since they are rarely encountered in the market.

NATURAL CEMENT

Those cements which are produced from a natural cement rock directly, requiring neither artificial proportioning nor admixture of other ingredients, are all in the class of Natural hydraulic cements. *Natural cement* is produced by the burning and subsequent pulverization of a natural cement rock (argillaceous limestone or other suitable rock in its natural condition) as found in various localities; that is, limestones which contain silica, alumina, and iron oxide in quantities greater than would be needed for Portland cement. The temperature required is considerably lower than that needed for the making of Portland cement, the heat of burning being insufficient to cause the material to start to fuse or melt. When thus roasted a clinker is formed, which when ground to a fine powder, is ready for immediate use. This powder has the property of setting under water, and contains a larger proportion of clay than hydraulic lime. The composition of Natural cement is extremely variable on account of the difference in the rock used in manufacture.

Brands of Natural Cement.—Natural cements are marketed under various names, depending generally on the locality where the cement rock is found. There are many brands of natural cement. Perhaps the most familiar are Akron, Fort Scott, James River, Louisville, Milwaukee, Roman, Rosendale, and Utica cements. The cement, for example, known as *Rosendale*—a term heard in New York and New England more frequently than Natural cement and sometimes applied loosely to all Natural cements—is made by burning magnesian limestone, of which very important deposits occur near the town of Rosendale, in Ulster County, N. Y. Louisville cement first came from Louisville, Ky. In other words, where the name of the district is a distinguishing mark, it is added to the name of the brand. Roman cement is the English name for Natural cement.

Improved Natural Hydraulic Cement.—In the Lehigh region are produced a few brands of "Improved Natural Hydraulic Cement," intermediate in quality between Natural and Portland, by mixing inferior portions of the product of the Portland cement departments, or a proportion of the regular Portland cement where the uniformity

in quality of the rotary kiln product obtains, with Natural cement clinker. Some of the works in the same region place upon the market second and third grades of Portland cement, some of which are made from the inferior portions of the clinker produced by the kilns and some mixtures of a portion of Natural hydraulic cement with the product of the Portland cement process. These mixed cements are of comparatively little importance, since they are rarely encountered in the market.

PUZZOLAN OR SLAG CEMENT

Puzzolan cement is the product resulting from grinding together, without subsequent burning, an intimate mixture of slaked lime and ground blast furnace slag or a natural puzzolanic substance, such as volcanic scoria (puzzolan, santorin earth, or trass obtained from volcanic lava or tufa). No burning is required, but the mixture is ground exceedingly fine. In chemical composition, slag cement consists of a combination of silica and alumina, mixed with hydrated lime. In Italy and some other parts of Europe, these cements are still made from volcanic tufa; but in America, blast furnace slag is used. The tufa or lava first used for this purpose appears to have been obtained at Pozzuoli, a small city lying near the base of the volcano Vesuvious For this reason the name *Pozzuolana*—or, as it is very commonly spelled, *Puzzolan*—was first given to this form of cementing material, and has since been extended so as to include all forms of slag cement which are made without burning.

Art. 2.—Delivery and Storage of Cement

Cement should be delivered in suitable packages with the brand and name of the manufacturer plainly marked thereon, and should be stored in a dry, well-covered and well-ventilated place and thoroughly protected from the weather.

DELIVERY OF CEMENT

The receipt of each shipment of cement must be noted and its correspondence with the report of the mill tests must be checked by a count of the number of bags or barrels, the presence of the laboratory inspection tags, brands and the car initials and numbers. Broken packages must be put to one side.

All cement should be furnished in the original package, either in first-class barrels or in stout paper, cloth or canvas sacks, which should be plainly marked with the brand or trademark of the manufacturer of the cement. It should be delivered in good condition, perfectly dry and free from lumps. No cement without the maker's brand should be received. The cement should be furnished in unbroken packages.

Aeration of Cement.—No cement should be shipped until at least forty-five days after its manufacture, except that in case of an emergency, and with the approval of the engineer in charge of the work, a shorter time may be allowed, but if the cement shows indications of unsoundness, a longer time may be required.

Certificate from Manufacturer.—The manufacturer should be required to furnish a certificate with each shipment of cement, stating (1) the date of manufacture; (2) the tests and analyses which have been obtained at the manufacturer's laboratory for cement taken from the day's grinding, of which the shipment forms a part; (3) that the cement does not contain any adulteration.

Deterioration of Cement in Transit.—The cement should be protected during transportation from rain and moisture. The packages should be kept unbroken and dry. For long shipments, or when in danger of being subjected to dampness, barrels should be used.

Packages.—No cement should be inspected or allowed to be used unless delivered in suitable packages properly branded. These packages may be either barrels or sacks, but should be well protected in either case from air and moisture. The packages should be of full specified weight. The gross weight should be marked on the barrels. In case the cement is wanted in barrels of different weight or in sacks, the gross weight should likewise be plainly marked thereon. Any broken packages may be rejected or used at the option of the engineer. All barrels or sacks must have the brand and maker's name distinctly marked. No mixing of brands should be allowed.

Capacity and Weight of Packages.—Portland cement barrels of different manufacturers vary in weight and capacity, due to differences in weight of cement, to differences in compacting the cement into the barrels, and to slight differences in sizes of barrels. The number of cubic feet of packed Portland cement in a barrel ranges from 3.2 to 4, and when loosely measured the volume may be increased between 20 and 30 per cent, the cement swelling considerably as it falls from the barrel. The generally accepted standard is that a barrel of Portland cement shall weigh 380 lbs. net, the barrel weighing 20 lbs. more, and that it shall contain 4 cu. ft. of cement measured loose (see Art. 14, page 150). Four bags (cloth or paper sacks) of cement are always assumed to be equivalent to a barrel; the regulation cloth sack weighing 1½ lbs. more, and containing 1 cu. ft. of cement measured loose. In other words, a sack of Portland cement is generally assumed to weigh 95 lbs.

Natural cements are lighter than Portland cements. The generally accepted standard is that a barrel of Rosendale or other eastern Natural cement shall weigh 300 lbs. net, the barrel weighing 20 lbs. more; a barrel of Akron, Louisville, Utica or other Natural cement west of the Allegheny Mountains shall weigh 265 lbs. net, the barrel weighing 15 lbs. more. Two or three sacks may constitute a barrel of Natural cement, usually three.

A barrel of Puzzolan cement is generally assumed to contain 330 lbs. net, and there are four sacks to the barrel.

Variation in Weight of Packages.—Leakage, as well as possible variations in individual cases, is allowable to an extent of 2 per cent, provided, however, that not more than 5 per cent of any portion of a shipment falls more than 2 per cent in weight below the standard or specified weight. If such a variation in weight occurs, it should cause rejection of the entire lot.

Delivery of Cement in Barrels.—Each barrel should be properly lined with paper or other material so as to effectually protect the cement from dampness. Any cement damaged by water to such an extent that the damage can be ascertained from the outside should be rejected *in toto* and the barrels unopened. Barrels containing a large proportion of lumps should also be rejected (see page 29). Broken barrels, otherwise satisfactory, may be counted half-barrels.

Delivery of Cement in Sacks.—Cement sacks are made of either cloth or paper, cloth usually being preferred, as paper bags are easily torn in handling, causing waste of cement. On the other hand, no care has to be expended in preserving paper bags, there is less loss by cement sifting out, and paper is less easily penetrated by moisture than cloth. Again, cloth bags may be returned, and will be re-purchased by the manufacturer: paper bags cannot be returned.

When cement is delivered in cloth bags, see that the sacks are of good quality and sound. Sacks made of open material, or worn, should with their contents be rejected. Any sacks broken or containing damaged cement may be rejected or accepted as a fractional sack, at the option of the engineer or the inspector. The consumer has an allowance made him for the return of empty cotton sacks, if made in accordance with the requirements of the Cement Company. The sacks must be kept dry, untorn and shipped back by freight.

When cement is delivered in paper bags, see that the sacks are strong and perfect in every respect.

Time of Delivery.—The contractor should be required to furnish the cement upon the work at least ten days before it is to be used, in order that time may be given to make the necessary tests.

Notice of Delivery.—The contractor should be required to notify the engineer when deliveries are to be made a sufficient time in advance to allow the engineer to have a representative present to sample the cement; or the contractor should be required to rehandle the cement in the storehouse for the purpose of obtaining samples, as directed by the engineer.

Rejection.—Cement showing signs of damage from moisture or other causes, such as caking, lumpiness or other defects, may be rejected without testing.

STORAGE OF CEMENT

Much care should be exercised in storing cement, since it readily absorbs moisture from the atmosphere, becoming lumpy or even a solid mass when kept in a damp place. Such cement is useless and must be thrown away. If the cement is to be stored in a damp place or near the sea, it should be packed in well-made wooden barrels lined with paper. Cement should not be placed directly on the ground, but on boards raised a few inches.

Deterioration of Cement in Storage.—To guard against deterioration the cement should be stored in dry, well-ventilated buildings and protected from moisture. Portland cement exposed to the atmosphere will absorb moisture until it is practically ruined, while the absorption of moisture by Natural cement will cause the development of

carbonate of lime, which interferes with its subsequent hydration. Cement in wooden barrels or in paper ordinarily keeps better than when packed in cloth. In all cases where cement has been long stored it should be carefully tested before use to ascertain whether it has deteriorated in strength.

If kept dry, cement will not be injured by long storage. If properly stored, Portland cement can be carried from one season to another without deterioration. In fact, contrary to former belief, instead of deteriorating, the quality is often improved by storage, especially with some makes that have shown considerable improvement. A period of storage diminishes the danger of unsoundness. Portland cement is rendered slower setting by long storage, and its tensile strength is increased if kept in a dry place free from draughts. In other words, long storage of cement in general tends to retard its setting, though not preventing its ultimate acquisition of full hardness and strength.

Proper Storage of Cement.—Select a storage place that is thoroughly dry. It is not sufficient that the cement be stored out of the rain; storage in a damp basement will soon ruin cement by caking it. Cement should be stored in dry, well-ventilated buildings for work of any magnitude; and for work of less importance it should be safely stored and protected from moisture in any form. The requisites for proper storage of cement are protection from dampness and excessive heat, and ventilation with plenty of dry air.

Weather-Tight Shed or Storehouse.—Cement must be stored in a shed or house of substantial design, where water or even dampness will not penetrate, the floor being dry and strongly built. The storehouse should be raised at least 6 in. above the ground, in order that a circulation of air under the floor may insure dryness, and the sides and roof must be water-tight to protect the cement from rain or the injurious effects of the elements, namely, air currents or other source of injury. Whatever the arrangement selected by the contractor may be, the inspector should insist upon a thoroughly damp-proof structure, with tight floors placed well above the ground. Moisture from the ground and from condensation is to be as carefully avoided as from rain and snow.

As an additional precaution, the cement should be stored on a platform, raised 6 or 8 in. from the floor, and away from the walls. Blocks should be laid on the floor, and planks placed over them, thus providing a platform slightly raised above the storeroom floor. On this platform the cement should be piled, and a covering of canvas or pieces of roofing paper should be thrown over the pile.

The temperature must be kept as low as possible in summer, as a temperature of from 80° to 100° F. may seriously interfere with the setting qualities of the cement, changing normal cement into extremely quick-setting cement. This knowledge should always be imparted to every one on the job, so that close watch may be kept of all batches of concrete deposited in the work.

The cement house should be sufficiently large so that the different lots of cement can be kept separate and readily accessible. The

specifications for the reception of cement shipments usually stipulate a definite time during which the shipments must be held on the work while undergoing test, and this necessitates ample storage facilities. Due regard should be given to the ease of getting the cement in and out.

The cement house should be provided with suitable scales for weighing the cement.

Storage of Cement in Carload Lots.—Cement is generally received in carload shipments of from 100 to 200 barrels, which should be stored in such manner as to enable each carload lot to be kept separate, so as to permit convenient access for sampling, counting of packages and removal. One carload should not be placed immediately upon another.

An ideal arrangement is to divide or partition the storehouse into a number of bins, each being of sufficient size to hold a carload and so arranged that each bin is readily accessible so that it may be filled or emptied with a minimum amount of labor. Over, or by the side of each bin, should be fastened a placard giving: (1) the brand of cement; (2) the number of packages; (3) the name and number of the car in which it was shipped; (4) the date when received; and (5) a space for the mark "accepted" or "rejected," with date.

Piling Cement in Storehouses.—When the cement is received, whether in sacks or barrels, it should, if possible, be piled in tiers in the storehouse in such a manner as to permit easy access to any package for proper inspection and identification. Each lot or consignment received must be piled by itself and its date or receipt, etc., plainly indicated as mentioned above. In other words, the cement should be piled in such a manner as to keep different consignments separate and apart and to give access for sampling and marking to any bag or barrel desired.

Cement may be piled in lots of a few hundred bags each, in regular tiers and rows, with each tier and row eight or ten bags high.

A 200-barrel car consists of 800 bags. If piled 10 high, 800 bags can conveniently be arranged in 5 rows of 16 bags each. Five times the length of a bag is about 9 ft. Sixteen times the width of a bag is about 20 ft. These figures require very snug piling. (See Fig. 1.)

If bags are piled 20 high, a somewhat greater length is necessary because the end bags must be arranged in the form of a "bulkhead" to resist the outward pressure. Such a bulkhead can best be made by laying a first row of headers, carried ten high with the bags behind placed as usual. The eleventh and succeeding tiers should also have an end row of headers, but they should overlap only about half the length of a bag of the lower ten tiers, extending over the first one of the cross rows. In the upper section the header row should be carried only eight high, and instead of seven rows of bags, only six should be used. The inside portion between the two end bulkheads should be made long enough to take 14 bags. With this arrangement, a pile will contain four bags less than 1,600 or two cars of 800 each. Each bulkhead should therefore have two extra bags placed on top and each will then consist of 170 bags. Each

interior vertical row across the pile will consist of 90 bags. The upper ten layers will contain 660 bags, and the lower section 940 bags. In the smaller pile, each tier parallel with the end of the pile contains 50 bags and it is a very easy matter to tally piles and keep track of shipments. With the higher piles the arithmetic is more complicated. A pile 20 bags high will measure very close to 10 ft. to the top. (See Fig. 1.)

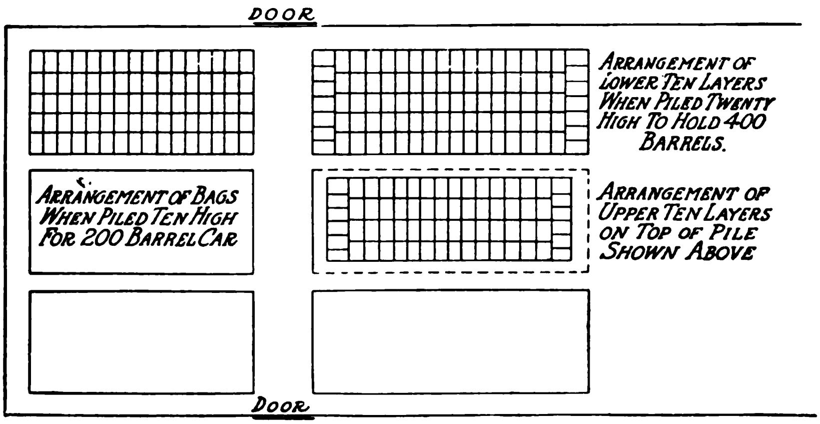


Fig. 1. Arrangement of Cement Bags in Storehouse.

If the cement is stored to any considerable height, the cement in the lower layers of bags sometimes become hard from compression, but no harm results from this. Cement in sacks can seldom be stored to advantage to heights greater than that of 20 or 22 full bags. The tiering of bags higher than ten requires extra labor in and out.

It will be found best to maintain a gangway about 6 ft. wide wherever cement has to be handled, but only about 2 ft. is enough to allow between piles, just sufficient for a tally man to make his way through.

Barrels may be stored by tiering in double rows, the barrels lying on the side. The end barrel on the bottom layer is placed against a "chock" firmly fastened to the floor. This chock should be a block of wood about 6 in. thick, beveled on one side to fit against the bilge of the barrel. A barrel is about 20 in. in diameter, so that a layer of any number of barrels will require 1 2-3 times as many feet in length. Conversely a length of any number of feet will house 3-5 times as many barrels. Each layer upward will contain one less barrel. The first layer will be about 20 in. high, two tiers will be about 36 in. high and each additional tier will add about 16 in. Thus any number of tiers will be 1 1-3 times as many feet high plus 4 in. Three tiers will be about 4 ft. 4 in. Six tiers will be about 8 ft. 4 in., and eight tiers will be 11 ft. This is about as high as it is well to carry such work. Barrels, if carried too high, require special

hoisting arrangements or long inclines and the barrels are apt to burst.

Where storage space is limited, the barrels may be numbered and sampled before they are placed in the storehouse, and they may then be piled solid, but this should be avoided whenever possible. Sacks cannot be so neatly stored, and since a smaller quantity is contained in a sack, they may be tiered so that every third or fourth sack is accessible.

Whatever the arrangement selected by the contractor, the inspector should insist upon the shipments being so stacked that each is accessible for inspection, marking and removal. That is to say, in piling cement it is wisest to separate each shipment and preferably each car load. The latter is the practice followed by many large users. No sample should be taken by the inspector until the cement is piled as herein mentioned, as it is his duty to insist that it be stored for ready removal of any lot condemned.

Different lots of cement must be kept separate, and under no conditions are subsequent lots of cement to be piled upon or in front of old cement already in the storehouse. Make the contractor use cement in regular order, the oldest first. By such a method of piling the amount used each day can be readily checked. See that previous lots of cement are used up before taking from the newer lots, unless specially directed otherwise by the engineer.

Ample Supply of Cement for Testing.—The contractor should be required at all times to keep in store a sufficient quantity of cement to allow at least ten days to elapse between the time of testing and the time of using (holidays and Sundays excluded). On large works, enough cement should be stored to last a month, in order that tests may be made, unless tests are made in the warehouse of the manufacturer.

Storage of Cement in the Open.—Storage of cement in the open should be limited to small quantities to be used immediately in the work. Bags of cement should not be piled on wet ground, sidewalks, pavements, etc., but on a platform, so that no part of the packages shall be nearer than four inches to the ground or pavement, and they should be stacked in compact piles which can be covered with tarpaulin in case of showers. The inspector should see that tarpaulins are provided and are ready for immediate use. In other words, if necessary to stack cement out of doors a platform of planks should first be made and the pile covered with tarpaulins. The cement must not be allowed to become wet or damp under any circumstances and must be effectually covered so that rain cannot reach it. Covering with planks is insufficient.

Art. 3.—Inspection and Tests of Cement

Although there is a tendency among cement manufacturers to improve the quality of their material, yet this does not relieve the necessity of careful inspection of cement delivered for important concrete work. Engineers should not consider the careful inspection

of cement purely as an additional refinement in connection with concrete construction, but as an absolute necessity, and should establish the unconditional rule of not permitting any cement to go into their work until they are fully satisfied by careful inspection that the cement is of good quality and capable of giving them the very best results. *All cement should invariably be inspected.*

Cement may be inspected either at the place of manufacture or on the work, or both, as may be ordered by the engineer. It may also be stopped in transit, on line of road, for a sufficient length of time to allow the lot to be sampled.

Field Tests.—In all instances, the cement is supposed to be tested at the mill. Test samples are taken from the several bins of the stock in storage, and when the cement has passed inspection, the material is taken from these bins and packed for shipment and delivery. Though cement direct from the mill is uniform and reliable, it may not remain so, and tests on the work are therefore necessary to determine its genuineness, that is, whether the article supplied is cement of a brand previously tested and accepted, and whether it is reasonably sound and active, the soundness of a cement being a quality that can be readily affected by improper storage, etc.

Sometimes, however, the cement is inspected in the warehouse or stock house at the manufacturer's. For works using an extremely large quantity of material produced at a single mill this may be advantageous, but otherwise it is impracticable, and furthermore is less accurate for the reason that the conditions surrounding the cement during transportation may be of such a nature as to alter its physical properties completely, and therefore the material tested may be radically different from that used in the work.

The preferred practice of engineers is to inspect and test the cement after it has been received in the field, both as a matter of convenience, and to insure against the substitution of inferior material after inspection.

On work of any importance it is good practice to make field tests of the cement (setting time and soundness principally, as described on pages 36 and 37) to guard against changes, and also compression tests on cubes made from concrete taken from the mixer or the wheelbarrows (see pages 248 and 303). These tests simply supplement the laboratory tests described on page 39 and cannot replace them, the compression test on the concrete as actually used is in itself a very excellent check on the efficiency of the mixture used, and gives also important information as to the proper time for removal of the forms as mentioned in Art. 19.

FIELD INSPECTION

In order to determine correctly the structural value of a shipment of cement, field inspection is very necessary. This should include an examination of the condition and weight of the packages; and of the condition and color of their contents; field inspection should also include an examination of the storage facilities for the cement.

Condition of Cement Packages.—Upon receipt of a shipment the

condition of the packages (either barrels or bags) should be observed. The packages should be fully intact, being in fairly good condition, without breaks or tears. The bags should be securely tied and, if so stipulated in the specifications, sealed properly with a lead seal.

If a special brand has been specified, all packages should be of this make, being plainly marked with the brand and name of the manufacturer. No cement should be inspected unless delivered in suitable packages properly branded. In other words, unbranded packages should be discarded and not allowed to enter the work.

If the specifications call for special sealing of bags, note the condition of such seals and whether or not they bear the inspector's mark. In case the seal and brand mark bear different names, the name on the seal should govern, but this should not be allowed to occur except in occasional instances.

Weight of Cement Packages.—A provision of many cement specifications is that the net weight of the packages shall not be less than a certain quantity. This weight should never be permitted to fall below the stipulated amount; for, since mortar and concrete are usually proportioned on the assumption of this weight (see Art. 14), the resulting mortar or concrete will be considerably weaker than intended. For the weight of cement packages, see Art. 2, page 22.

The determination of the net weight of packages being usually made in the field is considered as part of the inspection rather than the testing and consists of weighing a number of packages of cement at intervals. This may be done by weighing, say, 10 packages, either separately or together, and then the bags or barrels after the cement has been emptied from them, the difference being the net weight of the packages.

Condition of Cement in Packages.—A field inspection often enables a correct judgment to be formed of the condition of the cement as a whole, the field inspector often being able to form a more correct judgment than the tester in the laboratory.

The inspector should carefully note whether cement is lumpy and whether these lumps can easily be crushed in the fingers, as a possible indication of inferiority is the presence of lumps throughout the bulk of the material. If not easily crushed, the cement has probably been affected by dampness; but if easily crushed there is simply an indication of an old or well seasoned cement which generally appears rather lumpy.

On standing, cement gradually absorbs moisture from the air. This moisture is at first present in merely a minute and harmless state, but gradually it combines chemically with the cement; that is, in the same manner as when cement and water are actually mixed in practice. In the first condition, lumps usually appear, but these lumps can easily be crushed in the fingers and hence in making the mortar or concrete are entirely broken up and thus are not detrimental. If, however, the cement has been subjected to excessive dampness, or has been wet, lumps will be formed which are hard and difficult to crush. This probably indicates that chemical action has begun, the cement being hydrated and of inferior quality.

Cement containing lumps of this character is sometimes screened and the siftings used, but even in such cases the finer particles, which must have been subjected to nearly the same conditions as those that formed lumps, cannot be of as good a quality as originally. If an attempt is made to break up lumpy cement of this character and use it, it will be found to have lost most of its adhesive power and hardening qualities, and so to have lost the greater part of its strength and value as a building material.

While opinions are divided on this subject, it is usually advisable, and certainly the safest practice, to reject outright a shipment containing any appreciable quantity of hardened lumps or cakes; unless, of course, the conditions producing this result only affect a certain part of the shipment, in which case only that part need be rejected. Cement should invariably be rejected which has been wet, and caked into hard lumps. Old or well-seasoned cement is usually lumpy but the lumps are easily broken with the fingers, in which case the cement is entirely satisfactory.

Color of Cement in Packages.—It should also be noted whether the cement in the several packages is the same in color, thus precluding the possibility of other brands having been substituted in the cover specified, as a change in color may indicate a change in brand or quality. The color of Portland cement, ranging from bluish to yellowish gray, affords no criterion of quality in field inspection, except in so far as uniformity is concerned. (See page 46.)

If it is observed that the contents of different shipments or different parts of the same shipment are different in color, it is obvious that the shipments or parts of the same shipment are not all of the same material, thus pointing to a lack of uniformity. When this occurs, tests should be made of each grade of material to ascertain whether the cement is all acceptable, or whether it is a mixture of good and bad material.

Examination of Storage Facilities.—The storehouse should be frequently inspected to see whether the material is properly protected, so that it is impossible for the cement to deteriorate in quality while it is being held (see Art. 2, page 23). The storehouse must be kept dry at all times. Very often a shipment may show excellent tests but, by the time of their completion, the cement has been so mishandled as to have become worthless.

Report of Field Inspection.—A full report of the field inspection of every shipment should be sent to the testing laboratory with the sample and made a part of the permanent records (see page 39).

Rejected Cement.—Rejected cement should be removed at once under the supervision of an inspector, and some or all of the barrels or bags marked with a private mark so that it can be recognized if attempt is made to ship it back again.

Simple Method of Cement Inspection.—The following method of inspecting cement has been successfully employed in a number of cities and is here stated for its simplicity.

As soon as a carload of cement arrives for the contractor, the engineer should be notified at once. The bin in which the cement is

placed may be tagged with white cards, about 4x6 in. in size, bearing a serial number in large-size type and the word "HOLD," together with spaces for car number, number of bags in the car, and the bin number and date sample. When the cement has passed the necessary laboratory tests (see page 39), the white card may be removed and a pink one substituted, bearing the word "RELEASED." The inspector can thus see at a glance whether or not the contractor is using cement from an approved lot. When the bin is empty the pink card should be returned to the laboratory or to the engineer, as the case may be.

It is customary every Saturday for the inspector to mail to the laboratory or the engineer a postcard stating the number of bags used from each bin on his work. Records are kept at the laboratory or in the engineer's office and the number of bags turned in checked up with the original number unloaded into the particular bin.

If an additional precaution is considered necessary by the engineer in order to insure the use of tested cement only, the following method may be employed. The inspector should be required to attach a numbered tag, say 2 in. long, to each bag of the carload in question. The number should be the same for the whole carload. When the carload is approved by the laboratory or the engineer, the inspector is given the lot number of the released car. As the cement is used the tags are torn off by the inspector and at intervals turned in to the laboratory or to the engineer, where they are counted and recorded.

SAMPLING OF CEMENT FOR TESTING

Samples for testing should be furnished at such times and in such manner as may be required. The selection of the sample for testing, the number of packages sampled, and the quantity taken from each package, must be left to the discretion of the engineer, but each sample should be a fair average of the contents of the package from which it is taken.

The method of sampling must be that directed by the specifications, when there embodied. Careful and accurate sampling is necessary in order to obtain a true average of the shipment.

Methods of Sampling.—The sample for testing is generally taken in one of three ways: (1) An average sample from several packages; (2) separate samples, each from a single package, tested separately; (3) from a single bag taken at random.

Perhaps the most satisfactory method of sampling is to take a small sample from each of a number of bags, mix these lots together and separate the same into a convenient size for testing. For determining the characteristics of a carload of cement the individual samples may be mixed and the average tested. This mixing of samples is not considered advisable by many authorities except for the purpose of determining the characteristics of a shipment, as just stated. A mixture of samples will not reveal irregularities in quality.

The separate testing of a number of samples, each taken from a single bag, involves usually a large amount of unnecessary work,

especially if the lot represents a shipment of not more than 150 barrels. For the usual condition of shipments received in lots of 150 barrels or less, a single sample representing the average of the material is sufficient. Occasionally, however, the separate testing of a number of samples, each taken from a single bag, may be desirable, especially with a new brand, as a check on its uniformity. The inspectors of the cement intended for use in the New York Rapid Transit Subway make their tests at the mill on eleven samples taken from each bin, ten of which are from borings made at different parts of the bin, while the eleventh is a mixture of the other ten. Where time will permit, each sample may be tested separately, instead of being mixed.

Many specifications state that cement drawn from several samples shall not be mixed or mingled, but the individuality of each sample package must be preserved. All materials taken from the same sample package may, however, be thoroughly mixed or mingled and the tests be made therefrom as showing the true character of the contents of the sample package. United States Government specification for Portland cement requires that samples shall be tested separately for physical qualities, but for chemical analysis mixed samples may be used (see page 50).

A sample taken from only one bag or barrel in a shipment is manifestly unfair and inaccurate and hence the method should not be permitted.

Percentage of Barrels to Sample.—In securing a sample for testing, the essential point is to get one that will fairly represent the entire shipment whose qualities are to be determined.

The amount of cement which can be represented by a single sample for testing must be determined by each user of cement according to his knowledge as to the uniformity and reliability of the brand in use, and according to the character of the work in which the cement is to be used. In other words, the maximum size of a shipment of cement which shall be accepted on the test of a single sample, is a matter governed more by local conditions and the discretion of the engineer than by any fixed rules. In practice, since cement is usually shipped in car-load lots of 100 to 150 barrels, it is convenient to represent this quantity by a single sample, but this quantity is near to the safe maximum.

There is no uniformity of practice among engineers as to the sampling of the cement to be tested, some testing every barrel, others every fifth, and still others every tenth barrel delivered. Sometimes several tons of cement are accepted on a single test. As the improvements in methods have decreased the work involved in making the simpler tests, the tendency has been to test a larger percentage of the packages. The common practice is to take a small portion of material from every tenth barrel, or, what is the same thing, from every fortieth bag, since, with the usual packing of Portland cement, four bags to the barrel, one bag in forty is equivalent to one barrel in ten. The Committee of the American Society of Civil Engineers recommends that "where conditions permit," one barrel in every ten

be sampled. There is no necessity because of the smaller size of the packages for testing a larger proportion than one in forty, as the total weight will be about the same. Thus, in a carload shipment of six hundred bags, fifteen bags should be opened and sampled.

Although the sampling of one barrel in every ten is representative of average practice for larger lots, it is entirely too little for the small lots frequently received for short sections of sewer and other similar small jobs that are common in municipal work, where the entire amount of cement used may be only 30 or 40 bags, and which, according to this method, would be represented by a sample from only one bag. In other words, when tests are to be made on a shipment of only a few barrels, more packages than one in ten should be opened. When small lots of cement are used, a sample from every five or ten bags seems to be about right. That is to say, small samples should be taken from a great number of bags and mixed. This gives a better average indication of the cement. For mortar face work, samples are sometimes taken from each barrel.

When the shipment is large, say over 150 barrels, it is advisable to separate it into portions of not over this amount, and to sample each portion separately.

Selecting Samples.—In selecting the packages to be sampled, care should be exercised that they are taken from different parts of the pile, in order that the average sample or samples may fairly represent the car load or shipment. In other words, the individual samples from the several bags or barrels must be taken from various parts of the car; that is, at random.

If it is possible, the best time to take the samples is when the cars are being unloaded at the store-house, every bag in 30 or 40 being opened and sampled, or any other number that may be considered necessary.

In selecting cement for experimental purposes, care should be taken that the sample be representative of the material in the package, part being taken from the surface and part from the interior, in order to insure a fair exponent of the quality. In other words, the material taken from any one package should be an average of its entire contents, since the cement on its exterior is more liable to influences tending to change its properties than that on the interior, and also on account of the separation of coarse and fine particles in cases where the package has been subjected to much jolting in transportation.

Taking the Sample.—The sample should be taken in such a manner as to fairly represent the package as mentioned above, and for this purpose a "sugar trier" may be used, by which is obtained a core of cement about one inch in diameter and eighteen inches long.

Cement in barrels may be sampled through a hole made in the center of one of the staves, midway between the heads, or in the head, by means of an auger or a sampling iron similar to that used by inspectors of flour or sugar, which takes a small cylinder of the material from the surface to the center of the package. This auger or sampling iron is thrust into the hole made into the barrel, turned

around, pulled out, and the core of cement knocked out into the sample can, which is usually a tin box with a tight-fitting cover. The hole is then closed with a piece of tin firmly tacked over it.

As any tool used for boring cement barrels soon becomes dull, and as a sampling auger is sometimes difficult to sharpen, the author prefers to use an ordinary bit and brace to penetrate the barrel head or side, and then extract the sample with the sampling auger or sugar trier.

If in bags, the cement should be taken from the surface to center, using either the sampling auger or a long slender scoop of similar form provided with a handle.

Size of Sample.—The size of the samples depends on the number of tests to be made; for the ordinary tests as given in any one of the standard specifications, the amount should be between 8 and 10 pounds. Whenever cement is being used in car-load lots, a sample of at least 8 lbs. should be taken from each car. The aggregate amount of cement usually taken out of each car load is about 18 lbs., one-half of which is sent to the laboratory, and the other half is stored for reference by the engineer. Nine pounds are usually sufficient for the purposes of the tests in common use.

Labeling Samples.—Each sample should be sealed, and carefully labeled with the number of the sample or car number, the number of bags or barrels it represents, the brand of the cement, the purpose for which it is to be used, the date of delivery, and date of sampling.

Form of Label

Sample No...
Car Number..
No. of Barrels....................................
Brand ....
To be Used..
Delivered............191.. Sampled.............191..
By................

Care of Samples.—The cement, after sampling and before testing, must be well protected, as otherwise it may not be in the same condition as the cement in the packages. Samples exposed to heat, cold, dampness, or any other abnormal condition may seriously affect the results. Undoubtedly, many errors in cement testing are due to careless handling of the samples.

For storing the sample until it is tested, it has been found convenient to use covered tin cans holding about one pint, the cover of the can being labeled as mentioned above. Samples must be stored in a dry place until tested, being kept entirely away from the air and dampness till made into paste.

If duplicate samples have been taken, these must be kept in a dry place until the cement in that particular car has been used and the concrete is in place and thoroughly set.

Marking Packages.—All packages sampled must be properly marked, so they may be resampled if necessary. Every bag or barrel of cement should be marked by the inspector, or other precautions may be taken so as to identify the lot from which it is taken and to insure that no cement is delivered for use in the work which has not passed the required tests. Any package of cement which cannot be so identified may be rejected.

FIELD TESTS WITHOUT LABORATORY EQUIPMENT

In addition to the usual tests, the inspector should be required, from time to time, to make pats and balls of pure cement, and of cement mixed with sand, in order to satisfy himself that the cement going into the work is uniform in character and has not been injured by exposure to weather or in any other way. It is very easy for one lot of cement to differ very much from another lot of the same brand, and it is, therefore, very important that the inspector apply some rough tests to get an idea of how the cement is running.

Cement Testing House.—The contractor should be required to furnish a small, rough board building or room on the work for cement testing, furnished with shelves, racks, benches and work table. A steam pipe should be run into the same and sufficient heat furnished to prevent freezing during the day or at night in cold weather. The expense of such, together with the fitting up and warming of the same, will, of course, be included in the whole work.

Fineness.—Cement should have a clear, almost floury feel in the hand; a gritty feel denotes coarse grinding. Sift five ounces of cement through a standard test sieve of 100 meshes per lineal inch. Reject cement of which more than ½ ounce is retained on the sieve. This is very conservative and the limit may be made ¼ ounce, for many Portland cements are now in the market which will leave less than 4 per cent. A test by 200 mesh sieve with a 28 per cent limit is desirable but takes time. This sieve may be used in comparing the quality of two brands otherwise similar, choosing the finer cement.

Mixing Pats and Balls.—Secure a piece of glass about 20 in. square or larger (or a piece of sheet metal of similar size) and fix it on a bench or table. Secure an 8 in. brick mason's trowel, or devise a similar tool from a piece of still metal. If these are not available a wooden spatula may be cut from a shingle or similar piece of wood.

Take as much cement as is held when even full in an ordinary drinking glass, spread on the glass or sheet metal in a ring and pour in the center a little water from another glass which has been previously graduated by scratching on the outside the successive depths to which small, equal (not necessarily known) quantities of water fill it. This rough graduation can be easily accomplished and should be carried so far as to ascertain the total number of the small quantities required to fill the glass level full.

Turn the dry cement into the center of the ring containing the water until the water is all absorbed, after which work the mixture with the trowel or spatula by crushing it in small strips under the edge of the tool so held as to be nearly parallel with the glass or sheet metal, until the whole is of uniform consistency. This operation usually requires from two to four minutes. Add water little by little, constantly working the mixture until the latter conforms to the conditions described below for normal consistency. Note the amount of water as a decimal fraction (by volume) of the cement which is required to give the desired consistency. Multiply this fraction by 323 to obtain the percentage of water by weight. The temperature of the mixing water and of the cement should be as near 70° F. (usual house temperature in winter) as possible.

If weighing scales are available, use about ½ lb. of cement instead of the quantity held by a drinking glass, ½ lb. being equivalent to 277 grams.

If possible, secure a cylindrical graduate marked in cu. cm. instead of graduating a glass tumbler as above described. When the graduate is used, note the number of cu. cm. of water required to secure normal consistency as mentioned in the next paragraph. Since 1 cu. cm. of water of normal temperature weighs 1 gram, the percentage of water by weight required can be readily calculated.

Normal Consistency.—That amount of water is to be used in preparing test specimens which will produce a paste having the following characteristics:

1. It shall be firm, well bonded, shining and plastic.
2. It shall not change in consistency when worked double or triple periods of three minutes.
3. If dropped 20 inches from a metal trowel it shall leave the trowel clean.
4. A ball dropped 20 inches shall neither flatten appreciably nor crack. It should fall without losing its diameter more than ¾ inch.
5. Light pressure should bring water to the surface and the paste should not stick to the hand.

The normal consistency of a mixture of cement and water or a mixture of cement, sand and water, may also be determined by using the Vicat apparatus as described on page 53.

Setting Qualities.—Secure a piece of glass about 4 in. square and mold upon it a cement pat of normal consistency about 3 in. in diameter and ½ in. thick in the center and sloping to thin edges all around. This should be kept in moist air, free from sudden changes in temperature and draughts of air, and tested from time to time for setting or hardening, by noting the interval of time that elapses until the pat resists penetration under pressure of the thumb-nail. This point is where initial set ends and final set begins. It is the stage which immediately precedes the hardening process. Such tests should agree with the requirements stated in Art. 4. Reject cement which sets in less than 30 minutes. It may take three hours or more, but it will be better for most work if it sets in one hour.

The instant of "initial set" and "final set" may be determined as follows:

Secure a wire 1/12 in. in diameter. This is very close to 1¼ sixteenths of an inch and the head of a No. 2 pin has approximately this diameter. Or, the lead of a medium soft lead pencil can be stripped for a half inch from one end and made of the required size by the use of sand paper or equivalent. This wire or its equivalent should be fitted with proper weights so as to weigh ¼ lb. (4 oz.) avd. A cylinder of neat cement mortar mixed to the consistency described above, 1⅛ in. in diameter and 2⅜ in. long, will be very close to the required weight. Such a cylinder can be easily molded in a paper form rolled to the proper diameter, from a strip of paper of proper width. Secure another wire or equivalent, just one-half the diameter of the one above, and weight it with one pound. A cement cylinder 2 in. in diameter and 3 in. long will have this weight approximately.

The "initial set" is considered as having taken place when the surface of the pat will support a ¼ lb. weight resting upon the smooth flat end of a 1/12 in. diameter wire or equivalent, and the "final set" is considered as having taken place when the surface of the pat will support without appreciable indentation a 1 lb. weight resting upon the smooth flat end of a 1/24 in. diameter wire or equivalent.

If possible, a special set of Gillmore needles should be secured and employed in testing.

A simple test can be made by mixing some cement with just enough water to make it plastic, that is, of normal consistency, and rolling it into balls about the size of a walnut. Such cement balls should be soft, pliable, and damp on the surface, and should not feel warm at the end of 20 minutes. Cement failing in this is quick setting. Such cement often becomes slow-setting on being stored for several months. After the cement balls have set in the air for about two hours, place them under water for three or four days. If they gradually become hardened with no cracks, it is an indication of good cement. Any cement that does not endure this test at the end of a week is not of sufficiently good quality to make satisfactory work.

As a rule, the longer it takes the cement to set the stronger it will be. The inspector should reject any cement which fails to set properly in sample pats or balls.

Constancy of Volume.—Mold on clean glass pieces about 4 in. square (glass is essential) three pats of paste of the consistency described above and form into a flat circular cone about 3 in. in diameter and ½ in. high at the center, with thin tapered edges. The glass pieces with their pats should be covered with a damp cloth (the latter not allowed to touch the cement) for 24 hours, after which one specimen should be placed in water as near 70° F. as possible for 28 days, being observed at intervals.

Another glass with its pat should be left in the air at ordinary temperature for a similar period and also examined at intervals.

A third specimen should be boiled for at least four hours, preferably five hours, the water starting from its usual cool temperature.

A metal pail at least 6 in. in inside diameter should be used, the pail being provided with a loose cover (a board will do, unless the source of heat is an open fire). The glass should be supported above the bottom of the pail or vessel on a wire support or on a few small pebbles or pieces of brick.

To pass the above tests satisfactorily, the pats should remain firm and hard, and show no signs of radial cracking around the edges, distortion or disintegration. If any cracks show on the edges, or other deviations from the original shape of the pat, they indicate that the cement is of an expansive nature, and therefore not to be trusted. But because a cement will not stand this test is not in all cases to be condemned as useless, as expansion or blowing sometimes happens with newly made cement, and age will overcome it. A proper process of air-slacking or seasoning—placing it in a thin layer on a dry floor for a short time—may correct the defect.

If a sample fails in the boiling test it is safe to hold the shipment for at least 28 days and then make a second determination upon a fresh sample. If the second sample passes the test it indicates that the first sample needed seasoning. If the second test fails and the strength test is low the shipment should be rejected.

Blowing or cracks at edges of pats indicate free lime or magnesia. If lime is present, storage will improve the cement. Magnesia is injurious. Cement should invariably be rejected if the second sample pat (after a month or so seasoning) shows radiating cracks in the center, or shows blowholes on the surface, or curls up from the glass or cracks at the thin edges.

A simple test for soundness of cement, or freedom from tendency to shrink or expand during setting, is to take a glass tube or an ordinary cylindrical lamp chimney and fill it for a certain distance with well compacted cement paste, marking the end of the flat surface. If the cement shrinks, it will show by the mark, and if it swells, it will break the glass tube or lamp chimney; also when the paste is hard if a colored liquid is poured on top and filters in between glass and cement it shows contraction.

A modification of the above test consists in taking a lamp chimney with a large swell to it, standing it on end and filling it with dry cement and then pouring water on the cement. If the glass cracks, the cement is unfit for use in damp places. This test is very exacting and would condemn most cements on the market.

Purity.—"Provide a glass-stoppered bottle of muriatic acid, two shallow white bowls or two half-inch by six-inch test tubes, a glass rod and a pair of rubber gloves. Put in a bowl or a tube as much cement as can be taken on a five-cent piece; moisten it with half a teaspoonful of water; cover with clear muriatic acid poured slowly upon the cement while stirring it with the glass rod. *Pure Portland cement* will effervesce slightly and will give off some pungent gas and will gradually form a bright yellow jelly without any sediment. *Powdered limestone or powdered cement-rock* mixed with the pure cement will cause a violent effervescence, the acid boiling and giving off strong fumes until all the carbonate of lime has been con-

sumed, when the bright yellow jelly will form. *Powdered sand or quartz or silica* mixed with cement will produce no other effect than to remain undissolved as a sediment at the bottom of the yellow jelly. Reject cement which has either of these adulterants."*

Results.—The above tests should be conclusive as far as they go, and will cause the rejection of no good cements.

LABORATORY TESTS

Should the simple field tests stated above give unsatisfactory or suspicious results, then a full series of tests should be carefully made by professional inspectors on samples taken from the cement, either at the place of manufacture or on the work, in a manner analogous to that customary among engineers in the purchase of structural steel. None of the cement should be used until the report of the tests is received.

The laboratory should be selected by or subject to the approval of the engineer in charge of the work.

Sending Samples to the Laboratory.—Samples sent to the testing laboratory should be preserved in packages which thoroughly protect the cement from the atmosphere. No accurate results consistent with the quality of the cement as it exists in the barrel or bag at the time of sampling will otherwise be possible. Each sample must be accompanied by a manifest giving complete data of the same.

Method of Making Tests.—Tests, in general, should be made in accordance with the methods proposed by the Committee on Uniform Tests of Cement of the American Society of Civil Engineers, presented to the Society January 21, 1903, and amended January 20, 1904, with all subsequent amendments thereto, except where otherwise noted or required by the engineer. (See also Art. 5.)

Chemical Test.—A chemical analysis of the cement should account for at least 99 per cent of its component parts.

Fineness of Grinding.—A test to ascertain the fineness of the cement should be made by thoroughly sifting a sample of the cement through a covered nest of sieves composed of No. 100 on top and a No. 200 sieve below, and then weighing the quantities of cement retained on each of the two sieves. Fineness of grinding is to a great extent a direct measure of the cementing value, and with a well-burnt cement the high adhesive strength is developed by fine grinding that will intensify the activity of the greater proportion of the cement in the processes of solution, hydration, and crystallization that are operative in the hardening. (See Art. 5, page 50.)

Time of Setting.—A test to establish the setting time of cement should be made by mixing the cement with sufficient water to make a stiff paste and determining the time within which "initial" set should take place and the limits of time within which "final" or "hard" set must occur. (See Art. 5, page 53.)

Constancy of Volume or Soundness.—All cement must be constant in its volume, so that when the product once hardens it will retain its

* City Roads and Pavements, by Wm. P. Judson, Engineering News Pub. Co., 1902.

normal volume and not be subject to internal reactions, tending to cause a retrogression in the strength of the concrete. The decisive test of this property should be, that pats of neat cement, made on a glass plate and kept in a damp atmosphere for 24 hours, and afterwards immersed in cold water or subjected to the atmosphere of the laboratory, will not show any signs of warping or cracking at the edges, even after the lapse of a considerable period. This test may be accelerated by immersing the pats in a steam bath. (See Art. 5, page 61.)

Tensile Strength.—Tests to ascertain the tensile strength of the cement should be made both of neat cement and by mixing one part of cement to three parts of sand into briquettes, which are to remain in the molds for 24 hours, and then to be placed in water where they are to be kept for periods of 6 days, 27 days, etc., being broken at periods of 24 hours, 7 days, 28 days, etc., by testing machine. (See Art. 5, page 55.)

Other Tests.—Specific gravity test (see page 51) should be substituted for that of the weight of cement, as weight is no indication of quality. Tests of compression (see page 60) and adhesion are sometimes added.

Results of Tests.—The results of the tests made in the laboratory should be accepted as a final criterion for the acceptance or rejection of any particular shipment of cement.

Records.—Blank forms should be used for recording all tests and notations should be adopted to show for each test that the cement passed or failed or that the test was not made. No inference should be drawn from the lack of any entry other than that the recorder has neglected his duty.

Marking Rejected Packages.—After the report of the tests is received the rejected packages should be conspicuously marked with an "R" or a "C" and should be removed without delay; otherwise it is liable to be used.

MILL INSPECTION AND TESTS

When so required by the engineer, the cement may be inspected and tested at the place where the same is being manufactured or stored, and before it is shipped for delivery.

Supervision of Tests.—The cement should be tested in the presence of and under the direction of the engineer or his authorized representative and in accordance with the specifications as interpreted by the engineer.

Records at Disposal of Engineer.—All records kept by the manufacturer and which relate to the matters subject to inspection should at all times be at the disposal, both for reference or copy, of the engineer.

Scope of Mill Inspection.—Inspection may be required at the discretion of the engineer of the quantities of the raw material used in the mixture, the preparation of raw material for calcining, the calcining, the selection of clinkers for grinding, the grinding, the storing,

the barrels before packing, the barreling, the making of the barrels, the weight of the barrels ready for delivery, and the loading and shipment.

Scope of Mill Tests.—Tests may be required to be made to establish the identity and chemical characteristics of the raw materials used, of the degree of heat reached in calcining, of the chemical characteristics of the finished cement, fineness of grinding, specific gravity, setting qualities, constancy or soundness of volume, and, last but not least, of its tensile strength. The tests should conform to the standard requirements proposed by the Committee on Uniform Tests of Cement of the American Society of Civil Engineers, as stated above for laboratory tests. (See Art. 5.)

Test Samples.—The cement to be tested at the mill may be taken from the bins before barreling or from the cement after barreling, this being left entirely to the discretion of the engineer.

Routine of Mill Inspection.—The routine of mill inspection will consist of the manufacturer furnishing the cement in bulk or package, at option of the engineer, in sufficient time and quantities to permit all tests being performed before the cement will be required for shipment.

Cement Furnished in Bulk.—If cement is furnished in bulk, arrangements should be made which will permit of securing a sample satisfactory to the inspector. Provisions should also be made for sealing the spouts leading to and from the bins sampled.

Cement Sampled After Being Packed.—If the cement is sampled after being packed, each package should be plainly marked by the inspector for the purpose of identification, and should be so stored that it will be possible to obtain the packages represented by any one sample without it being necessary to handle others.

Setting Aside Special Bins.—The cement may be stored in bins set aside for the use of the purchaser. In case the manufacturer of cement has not the necessary facilities for setting aside special bins for this purpose until the time of shipment, samples may be taken while the cement is being packed, in which case the packages should be sealed immediately afterwards.

Storing, Sampling and Shipping.—All details of storing, sampling and shipping must be such as will meet the approval of the engineer or the inspector. When accepted cement is packed ready for shipment, each package of cement should be sealed by the inspector with a leaden seal for identification. In some cases, it is customary for the city or railroad company to furnish the leaden seals. The additional expense of this sealing is insignificant and should be required on any important piece of construction.

In order to guard against substitutions in transit, the cement should invariably be loaded under the eye of the mill inspector and the car may be sealed by him or the shipment otherwise marked by him in such a manner that any tampering with the individual packages or with the shipment as a whole can be easily detected. Notice of each shipment and a record of all identifying data should be forwarded to the engineer or to the inspector on the job. It will be the

duty of the job inspector to make certain that the shipment as received corresponds in every particular with the description furnished by the mill inspector.

Rejection of Accepted Cement.—In case cement is accepted on tests made on samples taken at the mill, it should be immediately rejected on its arrival at the work if it shows any signs of damage from moisture or other causes. In case packages already sealed are rejected, the seals should be immediately removed by the manufacturer or purchaser of the cement when notice of rejection has been received by him.

Field Inspection.—In cases where special conditions make inspection at the place of manufacture impracticable, inspection at the job may be substituted, subject, however, to the approval of the engineer. Field inspection has been discussed on page 28.

ACCEPTANCE REQUIREMENTS

No cement should be used in the work until it has been accepted by the engineer. The requirements to be fulfilled by the cement in order to be acceptable for construction work are stated in Art. 4.

Additional Requirements and Modifications.—All cement should be required to meet such additional requirements as to "hot water," "set" and "chemical" tests, as the engineer may deem advisable. The requirements for "set" may be modified where conditions are such as to make it advisable (see page 48). In other words, in addition to the usual tests, all cement furnished for the work should be subject to such other tests as may be necessary to determine whether the cement possesses the proper qualities for the particular work for which it is designated. (See page 48.)

Extended Tests.—The engineer may direct that tests be made, from time to time, of tensile strength and soundness, extending over longer periods than 28 days. If cement so tested shows a reduction of strength with increased age, or at any time fails in respect to soundness, the engineer may prohibit the future use of that brand of cement and require that another brand be substituted.

Rejection of Accepted Cement.—The fact that cement is satisfactory when tested is no indication that it will continue to be, hence cement which is not used for some time after test should be tested again, if there is any possibility that damp weather or other factors have affected its soundness. Marked deviation from uniform or characteristic results in tests may be considered cause for rejection of any lot of cement, even though the test requirements may otherwise be fulfilled.

Art. 4.—Test Requirements for Cement

The matter contained in this article has been taken largely from the author's book on "Cement Specifications," published by D. Van Nostrand Company, New York City.

GENERAL REQUIREMENTS

All tests should be made in accordance with the methods proposed by the Committee on Uniform Tests of Cement of the American Society of Civil Engineers, presented to the Society January 21, 1903, and amended January 20, 1904, and January 14, 1908, with all subsequent amendments thereto. (See also Art. 5, page 49.)

Fineness.—In each of the following requirements for fineness, it is assumed that thoroughly dried sieves are used.

Specific Gravity.—Specific gravity of cement may be used as an aid in detecting adulteration or underburning, but it is not necessarily conclusive as an indication of the quality of a cement.

Time of Setting or Setting Qualities.—The following requirements cover the time within which "initial" set should take place and the limits of time within which "final" or "hard" set should occur. Slow-setting cements should not materially increase in temperature during setting, whereas with quick-setting cements a marked increase is permissible.

Tensile Strength.—Cement which shows abnormally high strength on the one-day or seven-day tests may be regarded as unreliable, and therefore may be rejected. Cement must not be used unless it has satisfactorily passed the seven-day tests, but in case of failure it may be held for the result of the twenty-eight-day tests before being finally accepted or rejected.

Constancy of Volume or Soundness.—Cement should have the same constancy of volume in air as under water. Hence it must be tested under both conditions, except for Puzzolan cement, which must be tested for soundness under water. Tests should therefore be made on at least two pats or cakes of neat cement, prepared on a glass plate and kept in a damp atmosphere for twenty-four hours, and afterwards one of the pats immersed in water and the other kept in air at normal temperature.

Should the sample fail to pass the hot-water test, the engineer should either reject the lot or order a retest, or subject the sample to chemical analysis in order to determine whether the failure to pass the hot-water test was occasioned by free lime or other deleterious conditions. The engineer may withhold his approval until after the result of the twenty-eight-day test of the cake in cold water can be observed, or he may order a new boiling test from new samples drawn from the same lot, but from different packages. If the twenty-eight-day cold-water test or the second boiling test is unsatisfactory, the lot must be rejected. (See page 347.)

PORTLAND CEMENT

The quality of Portland cement depends upon the quality of the argillaceous limestones, or calcareous clays, or carbonate of lime and clay, their proportion in the mixture, the degree to which the mixture is burnt, the fineness to which it is ground, and the constant and scientific supervision of all the details of manufacture.

A cement that possesses the following properties may be consid-

ered a fair sample of Portland cement and would be suitable for any class of work.

Fineness of Grinding.—All cement must be finely ground, so that 100 per cent shall be passed through a sieve of 20x20 meshes per square inch.

At least 99 per cent should pass through a sieve of 50x50 meshes per square inch.

At least 92 per cent should pass through a sieve of 100x100 meshes per square inch.

At least 75 per cent should pass through a sieve of 200x200 meshes per square inch.

Specific Gravity.—The specific gravity of the cement, thoroughly dried at 100° C., should not be less than three and ten one hundredths (3.10), preferably between 3.12 and 3.25.

Time of Setting.—The time of setting may be determined with neat cement paste of normal consistency by the Vicat needle (see Fig. 3). The setting should not commence before thirty (30) minutes, nor terminate in less than one (1) hour nor more than ten (10) hours. For slow-setting cement, the initial set should occur in not less than one hour.

Tensile Strength.—Briquettes one (1) square inch in cross-section, made of normal consistency and kept twenty-four (24) hours in moist air, and the remaining time in water at normal temperature, +70° F., should show at least the following strength as determined from an average of five specimens:

(a) Neat Cement

Age.	*Strength.*
24 hours in moist air	175 lbs.
7 days (1 day in moist air, 6 days in water)	450 lbs.
28 days (1 day in moist air, 27 days in water)	550 lbs.

(b) One Part Cement, Three Parts Standard Sand

Age.	*Strength.*
7 days (1 day in moist air, 6 days in water)	150 lbs.
28 days (1 day in moist air, 27 days in water)	250 lbs.

(c) One Part Cement, Three Parts Sand

Age.	*Strength.*
7 days (1 day in moist air, 6 days in water)	110 lbs.
28 days (1 day in moist air, 27 days in water)	180 lbs.

The sand for test (b) should be standard quartz sand, which should pass a 20x20 mesh sieve and be retained on a 30x30 mesh sieve.

The sand for test (c) should be taken by the engineer or inspector from that used on the work and is intended as a test of the mortar.

Failure of Briquettes to Pass Tests.—Should the briquettes from a slow-setting cement fail, by a slight amount, to pass the twenty-four (24) hour or seven (7) day requirements for neat cement only, the lot in question should be held awaiting the results of the twenty-eight (28) day briquettes. Should the results of the seven (7) day tests on both neat and mortar briquettes fall below the requirements

stated above, the shipment should be rejected. If the strength of the twenty-eight (28) day mortar briquettes on a lot held awaiting the results of the twenty-eight (28) day neat briquettes does to show at least a ten per cent increase over the strength shown by the seven (7) day mortar briquettes, the lot should be rejected, even if the briquettes show a strength as herein stated.

Constancy of Volume or Soundness.—Circular pats of neat cement paste three (3) inches in diameter, one-half (½) inch thick at the center and tapering to a thin edge, should be kept in moist air for twenty-four (24) hours.

(a) A pat should be kept in air at normal temperature for twenty-eight (28) days.

(b) Another pat should be kept in water maintained as near 70° F., as practicable for twenty-eight (28) days.

(c) A third pat should be exposed to steam above boiling water in a loosely closed vessel for five (5) hours.

To pass the requirements, these pats should remain firm and hard, and show no signs of distortion, checking, cracking, discoloration or disintegration. In other words, pats left in the air or placed in water should during or after setting show neither expansion nor contraction, either by the appearance of cracks or change of form.

Failure of Pats to Pass Tests for Soundness.—In case the pats exposed to steam, on a lot of cement otherwise satisfactory, show signs of failure, two more pats should be made. If one of the extra pats fails after exposure to steam the lot should be held for twenty-eight days and resampled. If both of the additional pats are sound the lot may be accepted. In case a lot is held for resampling at the end of twenty-eight days because of failure of the steam pats, the lot should pass every requirement on the second sampling or it should be immediately rejected.

In case the normal pats on a lot of cement held awaiting the results of the twenty-eight (28) day briquettes show signs of disintegration, the lot should be rejected, even if it passes the other requirements.

Chemical Composition.—The cement should not contain more than one and seventy-five one-hundredths per cent (1.75%) of sulphuric anhydride or anhydrous sulphuric acid (SO_3), nor more than four per cent (4%) of magnesia (MgO). It must also contain no adulteration nor excess of ingredients which would render it unfit for use in the work.

The chemical composition of the cement should also be within the following limits:

Silica, 21 to 24%.
Alumina, 5 to 10%.
Iron oxide, 2 to 4%.
Lime, 60 to 65%.
Alkalies, not more than 3%.
Clay, 5 to 8%.
Loss by calcination, carbonic acid and water, not more than 2½%.

Microscopic Test.—The cement should show no signs of the presence of detrimental amount uncombined magnesia as indicated by the microscopic test.

Color.—The color should be a uniform bluish or greenish gray, free from yellow or brown particles. Blue checks or places indicate an excess of lime; dark green, a large percentage of iron; brown, an excess of clay. Yellow checks or places indicate an excess of clay or that the cement has not been sufficiently burned; and it is then probably a quick-setting cement of low specific gravity and deficient strength. (See page 30.)

NATURAL CEMENT

The Natural cements have a porous, globular texture. They do not heat up nor swell sensibly when mixed with water. They set quickly in air, but harden slowly under water, without shrinking, and attain great strength with well-developed adhesive force.

Fineness of Grinding.—Natural cement should be finely ground, so that not more than ten per cent (10%) by weight shall remain on a sieve of 100 meshes per lineal inch, made of No. 40 wire, Stubbs' gauge, and thirty per cent (30%) on a sieve of 200 meshes per lineal inch.

Specific Gravity.—The specific gravity of the cement, thoroughly dried at 100° C., should not be less than two and eight-tenths (2.8).

Time of Setting.—The time of "initial set" should not occur in less than ten (10) minutes, and it should reach its "final or hard set" in not less than thirty (30) minutes, or in more than three (3) hours. The time of setting may be determined by means of the Vicat needle (see Fig. 3) from pastes of neat cement of normal consistency, the temperature being between 60° and 70° F.

Tensile Strength.—Briquettes of cement, with one (1) square inch of cross-section, should develop the following ultimate tensile strength as determined from an average of five specimens.

Neat Cement

Age.	*Strength.*
24 hours in moist air	75 lbs.
7 days (1 day in moist air, 6 days in water)	150 lbs.
28 days (1 day in moist air, 27 days in water)	250 lbs.

One Part Cement, Two Parts Standard Sand

Age.	*Strength.*
7 days (1 day in moist air, 6 days in water)	120 lbs.
28 days (1 day in moist air, 27 days in water)	175 lbs.

One Part Cement, Three Parts Standard Sand

Age.	*Strength.*
7 days (1 day in moist air, 6 days in water)	50 lbs.
28 days (1 day in moist air, 27 days in water)	110 lbs.

For all tests with sand, standard quartz sand, which will pass a No. 20 sieve and remain on a No. 30 sieve, should be used.

Constancy of Volume or Soundness.—Circular pats of neat cement paste three (3) inches in diameter, one-half (½) inch thick at the center and tapering to a thin edge, should be kept in moist air for twenty-four (24) hours.

(a) A pat should be kept in air at normal temperature for twenty-eight (28) days.

(b) Another pat should be kept in water maintained as near 70° F. as practicable for twenty-eight (28) days.

These pats should remain firm and hard, and show no signs of distortion, checking, cracking, discoloration or disintegration after twenty-eight days in either air or water.

Boiling Test.—A boiling test may also be made by mixing pats as above, placing them at once in cold water, raising the temperature of the water to boiling in about an hour, continuing boiling for three hours, then examining for checking and softening.

Color.—Natural cements vary in color from light to dark brown, according to the character of the stone from which they are made. The color, however, gives no clue to the cementitious value, since it is due chiefly to oxides of iron and manganese which bear no direct relation to the cementing properties. A very light color generally indicates an inferior underburned cement.

PUZZOLAN OR SLAG CEMENT

Fineness of Grinding.—Cement must be finely ground, so that at least ninety-seven per cent (97%) shall pass through a sieve of 100x 100 meshes per square inch made of No. 40 wire, Stubbs' gauge.

Specific Gravity.—The specific gravity of the cement, thoroughly dried at 100° C., should be between 2.7 and 2.8.

Time of Setting.—The time of "initial set" should not occur in less than forty-five (45) minutes, and should acquire its "final set" in ten (10) hours. The time of setting may be determined by means of the Vicat needle (see Fig. 3) from pastes of neat cement of normal consistency, the temperature being between 60° and 70° F.

Tensile Strength.—Briquettes of cement, with one (1) square inch of cross-section, should develop the following ultimate tensile strength as determined from an average of five specimens.

Neat Cement

Age.	*Strength.*
7 days (1 day in moist air, 6 days in water)............	350 lbs.
28 days (1 day in moist air, 27 days in water)............	500 lbs.

One Part Cement, Three Parts Standard Sand

Age.	*Strength.*
7 days (1 day in moist air, 6 days in water)............	130 lbs.
28 days (1 day in moist air, 27 days in water)............	220 lbs.

For all tests with sand, standard quartz sand, which will pass a No. 20 sieve and remain on a No. 30 sieve, should be used.

Constancy of Volume or Soundness.—Circular pats of neat cement paste three (3) inches in diameter, one-half (½) inch thick at the center and tapering to a thin edge, placed on a glass plate, should not show any signs of warping or cracking after twenty-eight (28) days in water.

SILICA CEMENT OR SAND CEMENT

Silica cement or sand cement is a finely pulverized product resulting from the grinding together of silica or clean sand and Portland cement.

Test Requirements.—In all cases, the cement from which the product is made should be tested precisely as other cement.

ADDITIONAL REQUIREMENTS

Time of Setting.—The requirements for setting, as above stated, may be modified where the conditions of the work are such as to make it advisable.

Briquettes Subjected to Boiling Test.—If so required by the engineer, pieces of briquettes broken in tension tests of Portland cement, either neat or mortar, must remain hard and sound after the same exposure to steam or boiling water as stated for the pats or cakes.

SPECIAL REQUIREMENTS (QUICK-SETTING PORTLAND CEMENT)

A quick-setting Portland cement may sometimes be required for pipe joints or elsewhere. It should meet the following special requirements, all other requirements being the same as for ordinary Portland cement. (See page 43.)

Time of Setting.—It should require not less than fifteen (15) minutes nor more than thirty (30) minutes to develop initial set, and not over one (1) hour and thirty (30) minutes to develop final set under the normal conditions mentioned above.

Tensile Strength.—Tensile strength of neat cement should not be less than

24 hours (in water after hard set)..............100 lbs. per sq. in.
7 days (1 day in air, 6 days in water)........300 lbs. per sq. in.
28 days (1 day in air, 27 days in water)........450 lbs. per sq. in.

CEMENT USED IN SEA WATER

When cement is intended for concrete to be deposited under water it should be first subjected to the following test:

Setting Qualities.—Mix a small batch (about one cubic foot) of concrete of the proportion to be used in the work, and deposit it in a barrel of the water in which the proposed structure is to be built. If the concrete does not "set up" in a satisfactory manner the cement should be rejected. (See page 127.)

Testing Briquettes.—Briquettes left in molds and placed in water immediately after mixing must harden satisfactorily, so as to prove the fitness of the cement for setting under water. This test may be

made a comparative one by pitting the cement tested against brands of established reputation. Any cement not hardening under water to the entire satisfaction of the engineer should be immediately rejected.

Art. 5—Standard Methods of Testing Cement

The matter contained in this article has been taken largely from the author's book on "Cement Specifications," published by D. Van Nostrand Company, New York City.

GENERAL REQUIREMENTS

All tests should be made in accordance with the methods proposed by the Committee on Uniform Tests of Cement of the American Society of Civil Engineers, presented to the Society January 21, 1903, amended January 20, 1904, January 14, 1908, and January 17, 1912, with all subsequent amendments thereto.

Sampling Cement.—The sampling should depend upon the purpose for which the tests are made, and upon the previous tests that have been made with the same cement. Samples should be taken from different packages of each shipment, and as near as possible out of the middle of the barrel or bag. (See Art. 3, page 31.)

Screening Samples.—All samples should be passed through a sieve having twenty meshes per lineal inch, in order to break up lumps and remove foreign material.

Temperature.—All experiments should be carried on, as nearly as possible, at a uniform temperature of 65° F., except when tests are being made for the purpose of ascertaining the comparative strength of cements required for winter use. In other words, tests of cement should be made at a temperature of from 60° to 70° F. The temperature of the water and of the room in which the test pieces are made and tested should not be permitted to fall below 60° F.

Proportions.—All proportions should be determined by weight, as this is the most accurate method.

Water.—Ordinary fresh, clean water having a temperature between 60° and 70° F. should be used for the mixture and immersion of all test pieces or samples, unless the nature of the tests require that sea water be employed.

Record of Tests.—The temperature of the air and of the water used in mixing should be noted in the record of tests. The relative humidity of the air should also be observed and recorded. In every case the quantity of water used in mixing should be stated in the report.

CHEMICAL ANALYSIS

Chemical tests may be applied at the discretion of the engineer, and should pass the same to his satisfaction. All of the elements found should be indicated, without grouping, in the record of proceedings of the operation.

Method.—As a method to be followed for the analysis of cement, that proposed by the Committee on Uniformity in the Analysis of

Materials for the Portland Cement Industry, of the New York Section of the Society for Chemical Industry, reported in the *Journal* of the Society, Vol. 21, p. 12, 1902, and published in *Engineering News,* Vol. 50, p. 60, 1903, and in *Engineering Record,* Vol. 48, p. 49, 1903, should be followed, and in addition thereto the following:

"The insoluble residue may be determined as follows: To a 1-gram sample of the cement are added 30 cu. cm. of water and 10 cu. cm. of concentrated hydrochloric acid, and then warmed until the effervescence ceases, and digested on a steam bath until dissolved. The residue is filtered, washed with hot water, and the filter paper and contents digested on the steam bath in a 5 per cent solution of sodium carbonate. This residue is filtered, washed with hot water, then with hot hydrochloric acid, and finally with hot water, and then ignited at a red heat and weighed. The quantity so obtained is the insoluble residue."

To determine loss on ignition see Transactions, American Society Civil Engineers, Vol. LXXV, p. 676, Dec., 1912; also, Method Suggested for the Analysis of Portland Cement by the Committee on Uniformity in Technical Analysis, New York Section, Society for Chemical Industry, which, in addition to being found in the *Journal* of the Society, *Engineering News,* and *Engineering Record,* as stated above, may be found in the following works:

Hand-book for Cement Users, by Charles C. Brown, pp. 54-58. Published by Munic. Eng. Co., Indianapolis, 1905.

Cement and Concrete, by Louis Carlton Sabin, C. E., pp. 658-62, 2d edition, 1907. McGraw Pub. Co., New York City.

Circular of the Bureau of Standards, No. 33, United States Government specification for Portland cement, issued May 1, 1912. Department of Commerce and Labor.

A Treatise on Cement Specifications, by Jerome Cochran, C. E., pp. 77-81. D. Van Nostrand Co., New York City, 1912.

FINENESS OF GRINDING

The test for fineness is made by passing the cement through sieves of various meshes and measuring the residue retained in each. Those known as No. 100 and No. 200 sieves are the ones recommended by the Committee of the American Society of Civil Engineers, and should be used in determining the degree of pulverization of the cement. Sometimes a No. 50 sieve is used, but not often.

Sieves.—The sieves should be circular, about 20 cm. (7.87 in.) in diameter, 6 cm. (2.36 in.) high, and provided with a pan 5 cm. (1.97 in.) deep, and a cover. The sieves should be of brass wire having the following diameters: No. 100, 0.0045 in.; No. 200, 0.0022 in. The brass wire should be mounted on the frames without distortion. The mesh should be regular in spacing and be within the following limits: No. 100, 96 to 101 meshes to the linear inch; No. 200, 190 to 200 meshes to the linear inch.

Amount of Cement to Be Used.—Fifty grams (1.76 oz.) or 100 grams (3.52 oz.) should be used for each determination, the sample

being carefully dried at a temperature of 100° C. (212° F.) prior to sieving.

Hand Sieving.—The thoroughly dried and coarsely screened sample of cement should be weighed and placed on the No. 200 sieve, which, with pan and cover attached, should be held in one hand in a slightly inclined position, and mixed forward and backward, at the same time striking the side gently with the palm of the other hand, at the rate of about 200 strokes per minute. The operation should be continued until not more than one-tenth of 1 per cent passes through after one minute of continuous sieving. The residue should then be weighed and placed on the No. 100 sieve and the operation repeated. Some specifications require that the shaking be continued until no cement is seen to fall upon a sheet of white paper held below the sieve. In other words, the shaking should continue until no more passes through.

Mechanical Sifter.—A mechanical sifter, working automatically by jig motion, may be used instead of hand sieving. Many engineers are opposed to mechanical sieving, feeling that it is not as practicable or efficient as hand sieving. A great deal depends upon the kind of mechanical sifter used.

Examination of Sieves.—The sieves should be frequently examined, magnified, if practicable, to see that no wires are displaced, leaving apertures larger than the normal. They should also be kept thoroughly dry and clean.

Use of Shot or Small Weights.—The introduction of small weights or of large shot into the cement, while being sifted, is to be deprecated, as they tend to push an undue proportion of the cement through the mesh, to stretch the wires, and to increase the grinding. The Committee of the American Society of Civil Engineers recommends hand sifting with a few large steel shot, which should be removed before the final one of sieving.

Percentage of Fineness.—The weight of the material passing the sieve, plus the weight of the dust lost in air, expressed in hundredths of the original weight, will express the percentage of fineness. In order to determine this percentage the residue on the sieve must be weighed. The results should be reported to the nearest tenth of 1 per cent.

SPECIFIC GRAVITY

The test for specific gravity is made by weighing a given volume in air and noting the loss of weight when immersed in a liquid of known specific gravity, such as benzine, kerosene, alcohol or turpentine, which does not act on the cement; or by using a special specific gravity balance or a specific gravity bottle.

The sample should be carefully dried before the determination is made. Inasmuch as the differences in specific gravity are usually very small, great care must be exercised in making the determination. The determination of specific gravity should be made on the cement as received; and should it fall below the standard required in the specifications, a second determination may be made on the sample at a low red heat.

It cannot be too strongly emphasized that special care must be exercised in specific gravity tests.

Temperature.—The standard temperature for specific gravity determinations is 62° F., but for cement, testing temperature may vary between 60° and 80° F., without affecting results more than the probable error in the observation.

Apparatus.—Any approved form of volumenometer or specific gravity bottle, graduated to cubic centimeters with decimal subdivisions, may be used. The Le Chatelier apparatus will be accepted

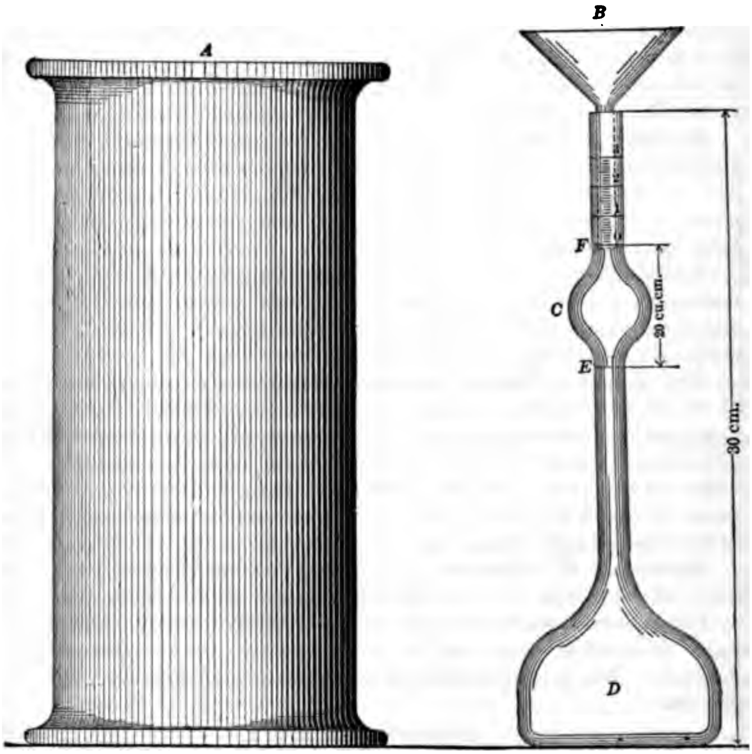


Fig. 2. Le Chatelier Apparatus for Determining Specific Gravity.

as satisfactory and is the one recommended by the Committee of the American Society of Civil Engineers. (See Fig. 2.) Accurate results may be obtained with the picnometer.

Benzine or Kerosene.—Benzine (62° Baume naphtha), or kerosene free from water, may be used in making the determination.

Determination of Specific Gravity.—Fill the specific gravity bottle to zero of the scale with benzine, kerosene, turpentine, or some other liquid having no action upon cement. Take, say, 100 grams of sifted cement that has been previously dried by exposure on a metal plate for twenty (20) minutes to a dry heat of 212° F., and allow it to pass

slowly into the fluid of the specific gravity bottle, taking care that the cement does not stick to the sides of the graduated tube above the liquid and the funnel through which it is introduced does not touch the fluid. The volume of the displaced liquid is then carefully read to the nearest fraction of a cubic centimeter.

The specific gravity is then obtained by dividing 100 grams by the displacement in cubic centimeters, or may be expressed by the formula:

$$\text{Specific gravity} = \frac{\text{Weight of cement, in grams}}{\text{Displaced volume, in cubic centimeters.}}$$

The specific gravity bottle, during the operation, should be kept immersed in water in a jar, in order to avoid variations in the temperature of the liquid.

The results should agree within 0.01.

NORMAL CONSISTENCY

In performing the tests for tensile strength, soundness, time of setting and temperature, the cement should be mixed with sufficient water to produce a semi-plastic mass of normal consistency. The determination of the proper percentage of water to be used in making pastes from which pats, tests of setting, briquettes, etc., are made, consists in measuring the amount of water required to reduce the cement to a given state of plasticity, or what is usually called the normal consistency.

Apparatus.—For the purpose of determining the normal consistency of a mixture of cement and water, or a mixture of cement, sand and water, the Vicat apparatus recommended by the Committee of the American Society of Civil Engineers should be used. (See Fig. 3.)

Determining the Normal Consistency.—The paste is considered to be of normal consistency when the cylinder of the Vicat apparatus, weighing 300 grams (10.58 oz.), penetrates to a point of the mass 10 millimeters (0.39 in.) below the top of the ring or level of the paste, great care being taken to fill the ring exactly to the top. The trial pastes should be made with varying percentages of water until the correct consistency is obtained.

Simple Method.—A simpler method for determining the normal consistency for test specimens is to mold a ball of the mortar in the hands to a plastic state and drop the same about 20 inches on the table. If the ball neither flattens appreciably nor cracks, the consistency is satisfactory. This process corresponds practically with the previous method. If dropped 20 inches from a metal trowel, the paste should leave the trowel clean. Light pressure should bring water to the surface, and the paste should not stick to the hand.

TIME OF SETTING OR SETTING QUALITIES

Time of set is found by making pats of the cement and noting the time which elapses from the moment water is added until the neat cement paste ceases to be fluid and plastic (called the "initial set"),

and also the time required for the paste to acquire a certain degree of hardness (called the "final" or "hard set"). This test should be made only on neat cement. The pats made for the soundness test (see page 61) may be used to determine the time of setting.

Vicat Apparatus.—The time of setting may be determined with neat cement paste of normal consistency by the Vicat apparatus recommended by the Committee of the American Society of Civil Engineers. (See Fig. 3.)

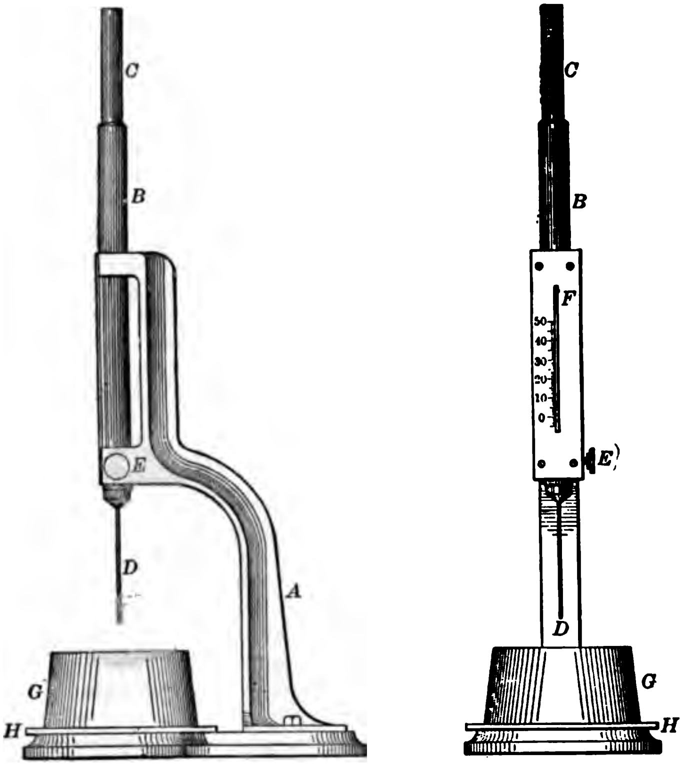


Fig. 8. Vicat Apparatus to Determine Setting Qualities of Cement.

Gillmore Needles.—The time of setting may also be determined by the Gillmore needles, consisting of weighted wires of given diameter, as follows: One-twelfth (1/12) of an inch in diameter weighted to one-fourth (1/4) of a pound, and the other needle one twenty-fourth (1/24) of an inch in diameter weighted to one (1) pound.

Amount of Water.—The quantity of water should be about as follows:

For Portland cement use 20 per cent of water.
For Natural cement use 30 per cent of water.
For Puzzolan cement use 18 per cent of water.

Sifting Cement.—The cement that is to be made in pats or cakes should not be sifted, but it is to be used exactly as it comes from the barrels or bags.

Mixing the Paste.—The required proportions of cement and water should be mixed thoroughly for five minutes, vigorously rubbing the mixture under pressure; time to be estimated from the moment of adding water. Some specifications require that a quick-setting cement be stirred one minute and a slow-setting one three minutes, using sufficient water to make a stiff paste.

Molding.—Two pats or cakes from the above mixture should be molded on glass plates, about three (3) inches in diameter and one-half (½) inch thick at middle and drawn to thin edges. The test pats or cakes should be made by rolling the cement into balls and then flattening.

Storage of Test Pieces.—The test pieces should be stored in moist air as soon as made, and there remain during the test. This should be accomplished by placing the test pieces on a rack over water contained in a pan and covered with a damp cloth, the cloth to be kept away from them by means of a wire screen; or they should be stored in a tight box not exposed to currents of dry air, i. e., a moist closet.

Methods of Testing.—The time of setting may be determined with the Vicat apparatus in the following manner:

A paste of normal consistency is molded in the hard rubber ring, and placed under the rod (B), the smaller end of which is then carefully brought in contact with the surface of the paste, and the rod quickly released. The cement is considered to have acquired its initial set when the needle ceases to pass a point 5 millimeters above the glass plate; and the final set, when the needle does not sink visibly into the paste.

The time of setting may also be determined by the Gillmore needles as follows: At the end of the time specified for "initial" set apply the needle one-twelfth of an inch in diameter weighted to one-fourth of a pound to one of the pats. If an indentation is made the cement passes the requirement for initial setting; if no indentation is made by the needle, the cement is too quick setting. At the end of the time specified for "final set" apply the needle one-twenty-fourth of an inch in diameter weighted to one pound. The pats should not be indented. In making the test the needle should be held in a vertical position and applied lightly to the surface of the pat.

BRIQUETTE MAKING

Tensile strength is determined by molding briquettes having a cross-section of 1 sq. in., made of neat cement and also of various mixtures of cement and sand, permitting them to remain in air and under water for specified periods, and then breaking in testing machines, and noting the breaking loads.

GENERAL REQUIREMENTS

Form of Briquette.—The form of briquette used for tensile strength determination should be in accordance with the American Society of Civil Engineers' Standard, which is in the shape of the figure 8, having a cross-section of one (1) square inch in the middle. (See Fig. 4.)

Molds.—The briquettes must be formed in suitable molds, the molds being made of brass, bronze, or some equally non-corrodible material, having sufficient metal in the sides to prevent spreading during molding. Gang molds, which permit molding four briquettes at one time, are recommended by the Committee of the American Society of Civil Engineers, as shown in Fig. 5.

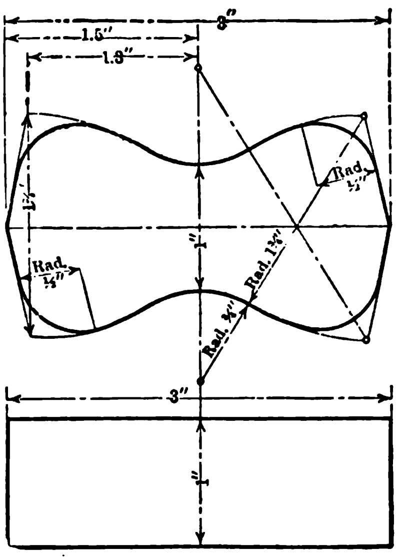


Fig. 4. Details of Briquette.

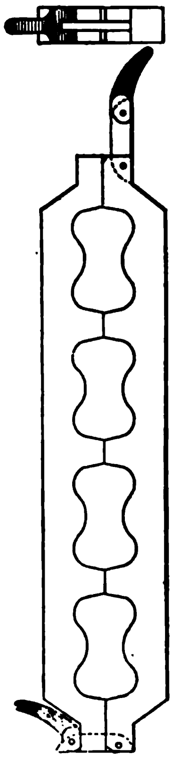


Fig. 5.
Details for Gang Mold.

Molding.—The molds in which the briquettes are allowed to set should be placed on a table of marble or polished metal (without blotting paper), or rest directly on glass, slate or other non-absorbent material. Both molds and slab should be well cleaned and rubbed over with a greasy cloth.

Böhme Hammer Apparatus.—Both the neat and mortar briquettes may be prepared by the Böhme hammer apparatus, which is a tilt hammer with automatic action. The hammer is driven by a cam wheel of ten cams actuated by a simple gearing. The steel hammer weighs about 4½ lbs., and when the intended number of blows have been delivered the mechanism is automatically checked, the proper setting having been made for this purpose before beginning the work. The number of blows for each briquette should be 150.

Removing Briquettes.—Considerable care must be exercised in removing briquettes before hard-set. After loosening the latch of the mold, tap gently the sides of the mold until they fall apart. The briquettes should be placed face down in water tank or pan.

Weighing Briquettes.—Briquettes should be weighed after taking them out of the molds so as to be assured of the regularity of their manufacture, and those which vary in weight more than 3 per cent from the average should not be tested.

Storage of Briquettes.—All briquettes should be kept one day in damp air, and submerged in clean water for the remainder of the time. (See page 59.)

(b) NEAT BRIQUETTES

Amount of Water.—Enough water should be used to insure a homogeneous briquette, but not enough to cause the cement to swell above the level of the mold or free water to flow to the surface when smoothed off with a trowel. The following amounts of water should be used for neat tests:

For Portland cement use 20 per cent of water by weight.
For Natural cement use 30 per cent of water by weight.
For Puzzolan cement use 18 per cent of water by weight.

Molding.—The molds should be filled about two-thirds full with the plastic mass and the cement pressed in with the thumbs, then filled completely, thumbed again, and leveled off smoothly even with the top of the mold. The mold should then be turned over, the cement thumbed once and finished level as suggested for the first side. The briquette should then be finished on both sides with a trowel.

(c) SAND BRIQUETTES

Proportions.—The proportions of cement and sand and water should in all cases be carefully determined by weight, not guessed at, as is often the case.

Standard Sand.—The sand should be natural sand from Ottawa, Illinois, screened to pass a No. 20 sieve (400 meshes per square inch), and retained on a No. 30 sieve (900 meshes per square inch), as recommended by the Committee of the American Society of Civil Engineers.

Amount of Water.—Just enough water should be used to form a homogeneous, dense briquette without showing a tendency for the cement or water to draw to the surface when finished with a trowel.

Portland cement requires water from 10 to 13 per cent by weight

of constituent sand and cement for maximum strength in tested briquettes.

Natural, about 15 to 17 per cent.
Puzzolan, about 9 to 10 per cent.

The percentage of water to be used in mixing Portland cement mortars for sand briquettes is given by the formula:*

$$y = 2/3 \frac{P}{n+1} + K$$

in which

y=Percentage of water required for the sand mortar.
P=Percentage of water required for neat cement paste of normal consistency.
n=Number of parts of sand to one of cement by weight, and
K=A constant which for standard Ottawa sand has the value 6.5.

The percentage of water to be used for Portland cement mortars containing 3 parts standard Ottawa sand, by weight, to 1 of cement is indicated in the following statement:*

Percentage of water for neat cement paste	Percentage of water for 1 to 3 mortars of standard Ottawa sand
18	9.5
19	9.7
20	9.8
21	10.0
22	10.2
23	10.3
24	10.5
25	10.7
26	10.8
27	11.0
28	11.2
29	11.3

Mixing.—The cement and sand in proper proportions should be mixed dry and nearly all the water specified above added at once, the remainder as needed, and mixed for five minutes by triturating or rubbing together the constituents of the mortar. This may be done by rubbing between the fingers, using rubber gloves for protection, or under pressure with a trowel. The mixing should continue for about five minutes.

Molding.—The mortar for making sand tests should be placed in the mold in four layers of about equal thickness, each of which should be compacted with a brass rammer weighing about one (1) pound and having a flat striking end of three-fourths (3/4) of an inch diameter or seven-tenths (7/10) of an inch square, with rounded

* United States Government specification for Portland cement, circular of the Bureau of Standards, No. 33, issued May 1, 1912.

corners. This rammer should be given a drop of one-half (½) inch, with thirty (30) drops for each layer evenly distributed over same.

STORAGE OF TEST PIECES

All test pieces for soundness and tensile strength should be placed in a moist closet or under a damp cloth as soon as made, and there remain until the end of the first twenty-four (24) hours. After the expiration of that time the test pieces should be placed in their respective places of storage, and there remain until completion of tests. The test pieces must be protected from currents of air and from the direct rays of the sun.

Storage in Water.—After twenty-four hours in moist air, the test pieces for longer periods of time should be immersed in water maintained as near 70° F. as practicable. Test pieces may be stored in tanks or pans, which should be non-corrodible material, and should be completely submerged during the whole period of hardening. The water should be renewed twice a week for the specified time, if running water is not available for a slow current.

If test pieces are immersed in sea water, renewal should take placed every two days during the first week, and after that every week.

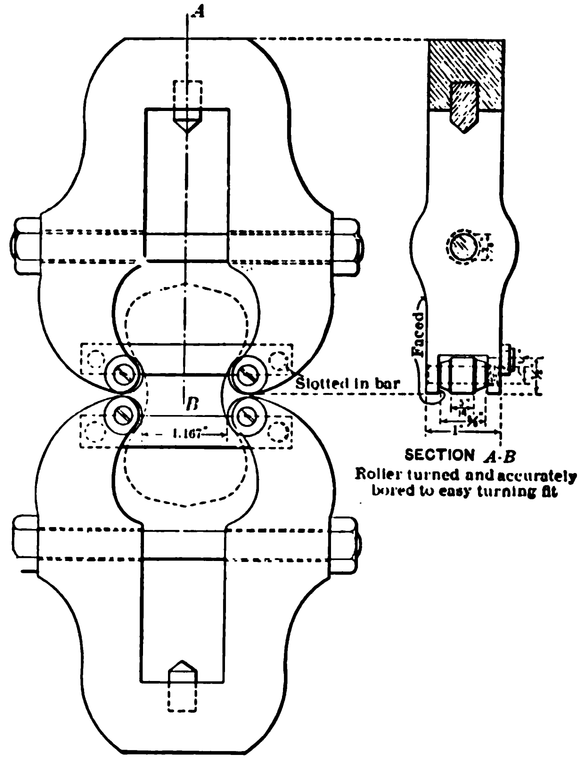


Fig. 6. Form of Clip.

TENSILE STRENGTH

Briquettes should be broken as soon as they are removed from the water or while they are still wet.

Form of Clip.—The form of clip shown in Fig. 6 should be used. It is the one recommended by the Committee of the American Society of Civil Engineers.*

Type of Testing Machine.—The tests may be made on any standard machine. Testing machines should be of the positive lever automatic type, so arranged as to apply the loads quietly and uniformly. Either Fairbanks or Riehle machines may be used.

Testing Briquettes.—Care must be taken in centering the briquettes in the testing machine. The load should not be applied too suddenly. The clips should be used without cushioning at the point of contact. The load should be applied at the rate of 600 lbs. per minute. The pull should be central, along the axis of the briquette.

No record should be taken of briquettes which do not break within 1/4 in. of the center.

The extreme variation between the mean of five briquettes should not be over 15 per cent.

COMPRESSIVE STRENGTH

Compressive tests are recommended by the Committee of the American Society of Civil Engineers.

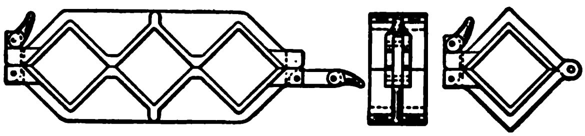


Fig. 7. Form of Mold.

Form of Mold.—The form of mold shown in Fig. 7 is the one recommended by the above Committee. Each face of the cube should be 4 sq. in. in area.

Testing Cubes.—The cube or test specimen should be placed in the testing machine with a piece of heavy blotting paper on each of the crushing faces, which should be those that were in contact with the mold.

Compressive tests should be determined after 28 days, it being impossible to accurately determine the cementing power, when comparing different kinds of cement, in a shorter period of time.

The briquettes should be prepared from a mixture of 1 part of cement and 3 of sand.

* Final Report of the Special Committee on Uniform Tests of Cement, Transactions, Am. Soc. C. E., Vol. LXXV, p. 685, Dec., 1912.

CONSTANCY OF VOLUME OR SOUNDNESS

The soundness of the cement may be determined by mixing the cement with water and molding same on glass into pats about three (3) inches in diameter, and about one-half (½) inch thick in center, with thin edges, not over one-eighth (⅛) inch at the circumference, and noting the condition of the edges of the pats; also by subjecting pats to a steam bath and observing whether they blow, swell or crack.

The signs of change in volume are generally shown after three days; in any case an observation of 28 days is sufficient.

Making Pats.—Pats or cakes of neat cement should be made by rolling the cement paste into balls and flattening to the form specified, care being taken to thoroughly work the cement so as to prevent any cracking at the edges on account of initial stresses. In molding the pats, the cement paste should first be flattened on the glass and the pat formed by drawing the trowel from the outer edge toward the center. Pats must be protected from drafts of air and from jarring. The pats, especially those of slow-setting cements, should be protected from drying out by storing in a covered box until the setting is finished.

Classes of Tests.—Tests for constancy of volume or soundness may be divided into two classes: (1) Normal tests, or those made either in air or water maintained in air at about 21° C. (70° F.); and (2) Accelerated tests, or those made in air, steam, or water at a temperature of 45° C. (113° F.) and upward.

Normal Tests.—(a) Cold-water tests consist in placing the pats after twenty-four (24) hours old in water maintained as near 21° C. (70° F.) as possible for twenty-eight (28) days.

(b) Air tests consist in subjecting pats after twenty-four (24) hours in moist air to the atmosphere of the laboratory, and observing at intervals.

Accelerated or Boiling Test.—The boiling test is made by placing pats after twenty-four (24) hours in moist air, on a screen in steam over boiling water in a loosely closed vessel for five (5) hours. Fig. 8 shows the apparatus for making an accelerated test for soundness of cement, recommended by the Committee of the American Society of Civil Engineers. Some specifications require that the pats be exposed to an atmosphere of steam for three hours, and then submerged in boiling water for three hours. Other accelerated tests use hot air, steam and hot water, steam or water under pressure, dry closets under a temperature above boiling-point, and a gas flame. The steam and hot-water tests are most uniform and satisfactory, and the boiling test is much the easiest of application.

Test Requirements.—There must be no change of color or form or checking, cracking or disintegration of the pats when subjected to the above tests.

Should the pat leave the glass plate, distortion may be detected best with a straight-edge applied to the surface which was in contact with the plate.

For additional tests for soundness, see Art. 3, page 37.

Art. 6. Significance of Tests of Cement

The matter contained in this article has been taken largely from the author's book on "Cement Specifications," published by D. Van Nostrand Company, New York City.

CHEMICAL ANALYSIS

Chemical tests and full quantitative analyses are strongly recommended, and preference should be given to cements of which analyses are furnished by the manufacturers.

Defective Portland cement usually results from imperfect manufacture, not from faulty composition. Cement made from very finely ground material, thoroughly mixed and properly burned, may be perfectly sound when containing more than the usual quantity of lime, while a cement low in lime may be entirely unsound due to careless manufacture.

The analysis of a cement will show the uniformity in composition of the product from individual mills, but will furnish little or no indication of the quality of the material. Occasional analysis should, however, be made for record and to determine the quantity of sulphuric anhydride and magnesia present in Portland cement.

Calcium Sulphate.—The ground clinker as it comes from the mill is usually quick setting, which requires correction. This is usually accomplished by the addition of a small quantity of more or less hydrated calcium sulphate, either gypsum or plaster of Paris. Three per cent of calcium sulphate ($Ca\ SO_4$) contains about 1.75 per cent sulphuric anhydride (SO_3), and as this has been considered by the best authorities the maximum quantity necessary to control time of set of Portland cement, specifications usually limit the SO_3 content to 1.75 per cent.

Standard specifications for Portland cement prohibit the addition of any material subsequent to calcination except the 3 per cent of calcium sulphate permitted to regulate time of set. Other additions may be difficult or impossible to detect even by a careful mill inspection during the process of manufacture, but as the normal adulterant would be ground raw material, an excess of "insoluble residue" would reveal the addition of silicious material, and an excess in "loss on ignition" would point to the addition of calcareous material when either is added in sufficient quantity to make the adulteration profitable.

Magnesia.—Chemical analysis should be made when it is suspected that magnesia is present in large amounts, or for mixed cements (see pages 45 and 49). The most dangerous feature in Portland cement is the presence of too much magnesia and an excess of free lime, the latter indicated by the cracks and distortions in the test pats or cakes, and the former in the deficiency of tensile strength of the briquettes. Over 5 per cent of magnesia is excessive and dangerous. Some specifications state that no Portland cement will be accepted which contains more than 2 per cent of magnesia in

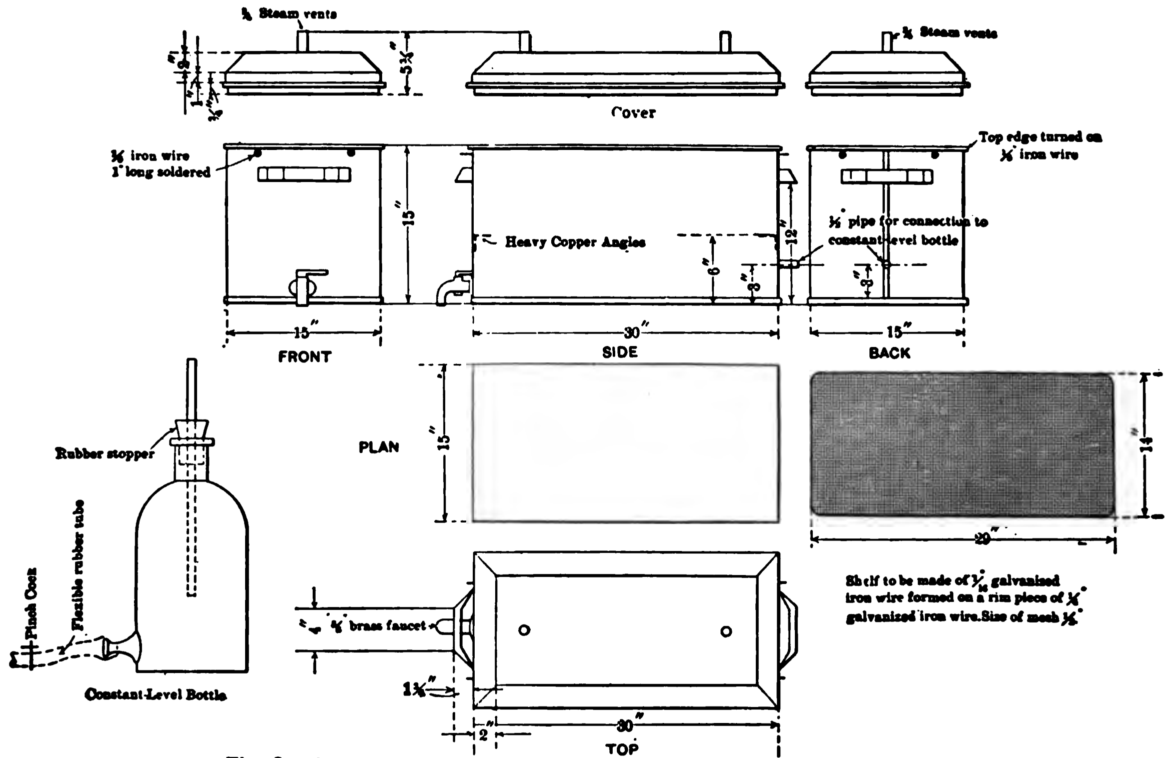


Fig. 8. Apparatus for Making Accelerated Test for Soundness of Cement.

any form. The maximum limit for magnesia should be set at 4 per cent, as it has been established that this quantity is not injurious and it is high enough to permit the use of the large quantities of raw material available in most sections of the country.

FINENESS OF GRINDING

The test for fineness of cement is important, because the finer the grinding, the more efficient and satisfactory will be the action of the cement, other things being equal. Not only is the activity of the cement increased by fine grinding, but the fine particles are necessary to fill small voids in the sand and thus render the mortar or concrete dense. The finer a cement is ground, the stronger that cement will be. In other words, the more finely cement is pulverized, all other conditions being the same, the more sand it will carry and produce a mortar of a given strength.

The most rigid fineness specifications could be filled by a cement which would be by many degrees too coarse. By a fine cement is not necessarily meant a cement so ground as to show a good sieve test, but rather a cement that contains a large percentage of flour. The same cement may also happen to contain a large percentage of coarse material, which is practically inert.

No sieve is fine enough to determine the flour in a cement, nor is there any other means of accurately and practically measuring the flour. Some cements grind easier than others; thus, although a larger percentage of one cement may pass the 200-mesh sieve than another, the former may have a smaller percentage of actual flour due to the difference in the hardness and the character of the clinker, and the method used in grinding. Thus the cementing value of different cements cannot be compared directly upon their apparent fineness through a 200-mesh sieve. With cement from the same mill, with similar clinker and grinding machinery, however, it is probable that the greater the percentage which passes the 200-mesh sieve, the greater the percentage of flour in that particular cement.

Use of Plates.—Plates with round holes are to be preferred to wire screens, but it is difficult to manufacture them.

Mechanical Sifter.—Mechanical shaking has not been found satisfactory, especially for fine cement, and hand shaking is to be preferred.

SPECIFIC GRAVITY

The specific gravity determination cannot in itself be considered an indication of the adulteration of Portland cement, until placed in comparison with other tests indicating quality. It may be used as an aid in detecting adulteration, but it is not necessarily conclusive as an indication of the quality of a cement. The test will not detect a small adulteration nor adulteration with a material of high specific gravity. The test is of some value in dealing with one brand of cement, but its determination is not absolutely necessary.

The specific gravity of a Portland cement will vary with the constituents of the cement, especially with the content of iron oxide. Thus the white or very light Portland cements, containing only a fraction of a per cent of iron oxide, usually have a comparatively low specific gravity ranging from 3.05 to 3.15, while a cement containing 3 to 4 per cent or more of iron oxide may have a specific gravity of 3.20 or even higher.

The specific gravity of cement is lowered by underburning, adulteration and hydration, but the adulteration must be in considerable quantity to affect the results appreciably. Specific gravity tests should not be taken as a direct indication of underburning. A comparatively low specific gravity does not necessarily indicate that a cement is underburned or adulterated, as large percentages of raw materials could be added to a cement with a normally high specific gravity before the gravity would be reduced below 3.10.

The specific gravity of Portland cement depends upon its age and the opportunities which it has been afforded of absorbing water and carbonic acid from the atmosphere. Its specific gravity is lowered by exposure, because of the absorption of water and carbonic acid, hence the necessity of drying the cement before testing. It has been found that the absorption of moisture and carbon dioxide does not appreciably affect the cementing value of the material; in fact, many cements are unsound until they have been aged. Thus a redetermination is permitted in standard specifications upon a sample heated to a temperature sufficient to drive off any moisture which might be absorbed by the cement subsequent to manufacturing, but would not drive off any carbon dioxide nor correct underburning in the process of manufacturing the cement.

The value of the specific gravity determination lies in the fact that it is easily made in the field or laboratory, and when the normal specific gravity of the cement is known, any considerable variation in quality due to underburning or the addition of foreign materials may be detected as mentioned above.

NORMAL CONSISTENCY

In order to insure the necessary uniformity in carrying out tests for setting, soundness or tensile strength, etc., it is exceedingly important to use a proper percentage of water in making the pastes from which pats and briquettes are made. In fact, the results are vitally affected if the proper amount is not used.

Determination.—The determination consists in measuring the amount of water required to reduce the cement to a given state of plasticity, such that the paste shall leave the trowel cleanly and in a compact mass. That is to say, when the cement is gauged with the proper amount of water it shall form a smooth, easily worked paste that does not require the trowel to be scraped off or otherwise handled to clean it from the gauged cement. The trial pastes must be made with varying percentages of water until the correct consistency is obtained.

TIME OF SETTING

This test is seldom used as a basis of comparison, but merely to see if the cement is sufficiently slow in its setting action to be properly manipulated or whether it hardens rapidly enough to satisfy the requirements of the work on which it is to be used. The setting time of cement has been found to bear an important relation to its strength.

Slow-Setting Cements.—If a cement is found to be very slow in setting, it is probable that an excess of lime has been used or that the material has been imperfectly ground. Slow-setting cements are apt to be stronger than those which set more quickly.

Quick-Setting Cements.—Quick-setting cements, that is, those that set inside of four hours, are apt to be overclayed and are apt to contain less of the active materials to which cement owes its strength. That is to say, if a cement sets very quickly by heating during the mixing process, and is found to be of low tensile strength, it is probable that an excess of clay has been used or that the cement is low in sulphuric acid (SO_3). Quick-setting cements are not necessarily prompt hardeners; they are usually the reverse.

"Flash Set."—If a cement has a "flash set" or is extremely quick in this particular but hardens only very slowly, there is a probability that an excess of alumina is involved, usually combined with overburning.

Temperature.—In order to obtain uniform results in determining the setting of cement, it is of importance to carry out tests at a mean temperature, of both air and water, of 60° to 70° F., as the setting is influenced by the temperature of the air and of the water used in mixing; a high temperature quickens the setting, a low temperature, on the other hand, retards it.

TENSILE STRENGTH

Experience has shown that a great variety of results is obtained with the same cement with different manipulators, owing to the varying degree of compression used in filling the molds, varying all the way from the pressure of the finger to hard ramming, and to varying lengths of time used in mixing, as well as the type and condition of the testing machine. Consistent results can only be obtained by exercising great care in molding and testing the briquettes. It may be considered good laboratory practice if the individual briquettes of any set do not show a greater variation from the mean value than 8 per cent for sand mixtures and 12 per cent for neat mixtures.

Neat Cement Tests.—The neat cement tests are of less value than those of briquettes made of sand and cement. Neat tests afford more information as regards the properties of the cement itself than as regards how it will behave in the work; to get practical information regarding this, mortar and concrete tests are necessary, as the testing of the aggregates to be used is of more practical value. The strength of cement should not be gauged by the results of neat tests, but

should invariably be made to depend upon long-time experiments on sand mixtures.

Seven-Day Test.—A high seven-day sand test is an indication of prompt hardening of cement.

Twenty-eight-Day Test.—Cement that will stand a high test for seven days may have an excess of lime, which will cause it to deteriorate. The twenty-eight-day test is, therefore, very useful. Any cement not showing an increase of strength in the twenty-eight-day tests over the seven-day tests should be rejected.

Extended Tests.—Longer tests than twenty-eight days are of value when it is desired to learn the rate of hardening.

CONSTANCY OF VOLUME OR SOUNDNESS

The test for change of volume is very important, for expansion in any work into which cement enters would be fatal to reliability. It is therefore highly essential to determine such qualities at once, tests of this character being made for the most part in a very short time. The purpose of this test is to detect those qualities in a cement which tend to destroy the strength and durability.

Thin pats or cakes of neat cement allowed to take final set in moist air should withstand indefinite exposure in water or air at any temperature to which the cement may be exposed in the work, without giving any evidence of swelling, checking or warping out of shape, or softening. The constancy of volume of all cement should be perfect.

Boiling Test.—The boiling-water test is designed to ascertain the durability of the cement, and is intended to show in a few hours what would take a long period otherwise. This test is supposed to show whether an excess of free lime is in the cement. Of two or more cements offered, all of which will stand the fresh-water pat test for constancy of volume, the cements that will stand the boiling test also are preferred. An unfavorable boiling test should not itself be a cause for rejection, but that chemical analyses be made and the boiling test repeated at a later period. (See page 347.)

Unsatisfactory Boiling Test.—If a sample fails in the boiling test, the shipments should be held for at least 28 days and then a second determination made upon a fresh sample. If the second sample passes the test it indicates that the first sample needed seasoning. If the second test fails and the tensile strength is low, the shipment should be considered as suspicious. If a cement fails in a boiling test it is probable that an excess of lime has been used or that the material has been imperfectly ground.

Examination of Pats for Cracks, Etc.—In examining pats for cracks, the fine cracks found on the surface, that cross and recross each other, are not due to expansion, cracking and disintegration of the cement, but are merely the result of changes of temperature. The cracks due to expansion, cracking and disintegration are wedge-shaped, running from the center and usually accompanied by a certain amount of disintegration, especially at the edges.

Shrinkage Cracks.—These are usually caused by the use of too wet a mixture, or produced by too great rapidity of drying. Dry air will usually produce this effect, so that such cracks indicate improper manipulation and not dangerous properties in the cement. (See Fig. 9.) Shrinkage cracks may extend across the center of the pat, but can be distinguished from expansion cracks. No shrinkage cracks should develop after the first 24 or 48 hours.

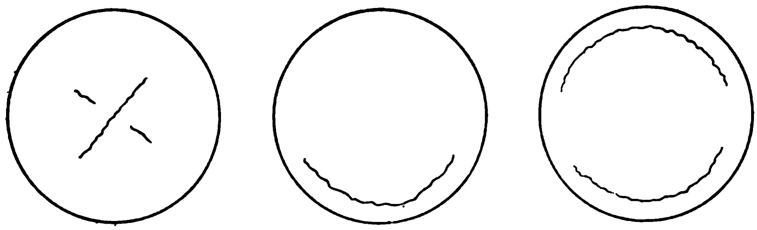


Fig. 9. Harmless Shrinkage Cracks.

Pats Which Have Curled Up at Edges.—Cracks caused by the curling of the edges of the cement away from the glass while the pat still adheres is a common occurrence in air pats and should not be considered dangerous unless extreme in character. It should not occur in water pats. If such cracks are found in water pats they denote the existence of qualities which should ordinarily condemn the sample. (See Fig. 10.)

Fig. 10. Condition Due to Expansion (Harmless in Air Pats).

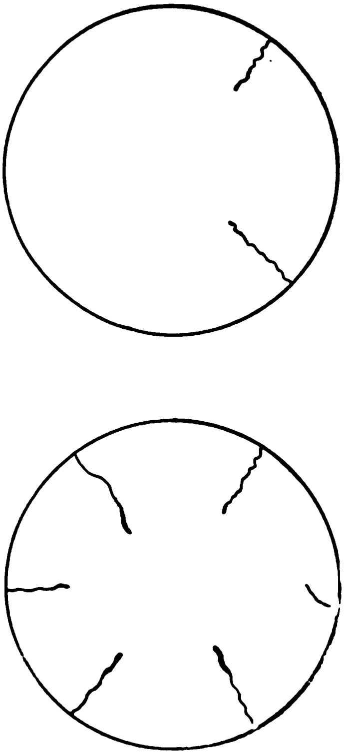
Pats Which Have Left Glass.—Pats which have left the glass because of the mere lack of adhesion in either air or water pats should not be considered dangerous. A curvature greater than a quarter of an inch caused by expansion or contraction should be sufficient to condemn the same. (See Fig. 11.)

Fig. 11. Pats Which Have Left Glass.

Pats Causing Glass to Break.—Occasionally the glass will break, while the cement pat still adheres to it. This is not usually indicative of poor quality.

Radial Cracks.—Radial cracks incident to incipient disintegration should always warrant rejection of the sample. (See Figs. 12 and 13.)

Blotching.—If a pat is blotched, special investigation should be given to its cause, which may be either adulteration or underburning.



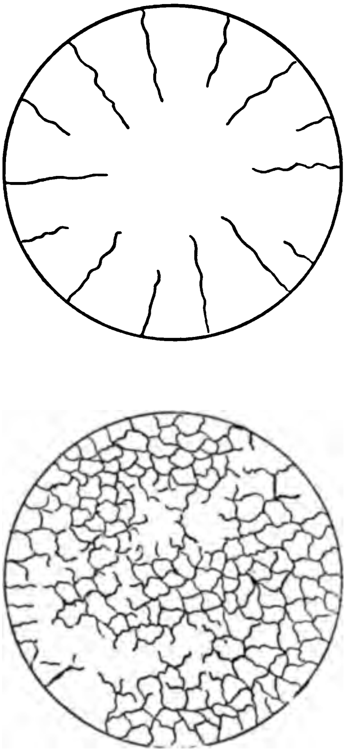


Fig. 12. Incipient Disintegration. **Fig. 13. Complete Disintegration.**

Interpretation of Results.—To properly interpret the result of the constancy of volume or soundness tests requires a large and varied experience, which is undoubtedly the most difficult phase of the testing of cement. The presence of radial cracks of incipient disintegration in normal pats is always sufficient to warrant condemnation, while, of course, complete disintegration would cause the rejection of the cement.

CHAPTER II

INSPECTION OF SAND, STONE AND MISCELLANEOUS CONCRETE MATERIALS

Art. 7.—General Stipulations

The aggregates used with cement in the formation of concrete are generally sand or stone screenings and broken stone or gravel.

Classification of Aggregates.—Aggregates are commonly divided into two classes, the one called fine and the other coarse: this is a purely conventional separation. *Fine aggregate* is generally taken as that part of the material which will pass a screen having ¼-inch meshes and sizing from there on down to granules no larger than pin points. It consists generally of sand, but may also consist of gravel or stone screenings (see Art. 8). *Coarse aggregate* consists of material larger than ¼ inch, that is, particles failing to pass the ¼-inch screen, and may be gravel, broken stone, cinders, slag or any hard, durable material (see Arts. 9, 10 and 11).

GENERAL REQUIREMENTS

Selection of Aggregates.—The importance of selecting good aggregates for concrete is second only in importance to the selection of cement, forming as it does by far the greater part of the structure. It is to be regretted that engineers have not more generally acquainted themselves with the value of various aggregates, as regards their adaptation for use in concrete work. It cannot be too strongly insisted that every possible precaution be used in the selection of materials which go into the concrete. While the selection is ordinarily governed by the materials obtainable in the locality, careful consideration should be given to the character of the work and the desired qualities in the finished construction. The gradation in size, proportioning, etc., of these materials, which is treated later, has an important bearing upon the density and economy of the work, and all reasonable means should be taken to secure as good material as is available. Local materials should invariably be carefully tested and not employed if found unsuitable, unless their inferior quality is taken into account in designing the structure. The materials used should give uniform character and color to any structure or group of structures.

Specifications for Aggregates.—Specifications for aggregates usually stipulate the kind, the mineral nature of the particles, the size and shape of the particles, the cleanliness, the amount of voids and

whether or not it shall be screened or washed. Specifications vary in their requirements and the inspector must be bound by the particular specifications. Care must be taken that the materials used are exactly what are called for in the specifications, and that each material will meet the specification requirements. In other words, it is the inspector's duty to see that the aggregate used meets the requirements of the specification and to make certain that no other aggregate is used in the work.

Determinations for Aggregates.—Aggregates, being inerts, do not permit of or require as intricate and detailed analysis as cement (see Art. 5), which is chemically very active. The requirements are, therefore, chiefly physical, and are, for the most part, concerned with the hardness and durability, the size and grading of the various particles, cleanliness and amount of voids. All these things admit of fairly easy and accurate determination, a fact which tends to make the inspector careless about making any determination at all; nevertheless, they are quite important and, if good results are to be consistently realized, require attention equally as much as cement. For determinations for sand, see page 93; for gravel, see page 108; and broken stone, see page 118.

Durability of Aggregates.—The life of the concrete is dependent upon the aggregates; materials soft, fragile, brittle, easily acted upon by the agencies of decay, and poor resistants to fire and gases, cannot make enduring concrete, no matter how well mixed,—the weaker the individual particle, the weaker the mass as a whole. In other words, the strength of the whole mass is, in a degree, only the strength of each individual particle, and, like a phalanx, is dependent on intimate association of all units. Aggregates should be such that they will undergo no future alterations, either in disintegration due to chemical changes, or breaking of particles under the tamper, due to the presence of cracks or bruises received at the crusher.

Shape of Particles of Aggregate.—Other things being equal, rounded aggregates give greater density and a lower percentage of voids, since the compactness increases as the particles become more rounded. The question of shape, however, is more theoretical than practical; theoretically, the spherical shape is ideal; practically, while aggregates of rounded gravel and sand make a little stronger and denser concrete, irregular, jagged particles, like broken stone, give satisfaction, indeed may be preferable on account of superior quality. In other words, the shape of the particles of aggregate has little effect on mortar, except as to density (see page 131); but concrete is affected by the shape of the particles, especially of coarse aggregate; flat, thin particles being undesirable.

Size of Aggregate.—The larger the maximum size of aggregates, the denser and stronger will be the concrete; but experience has shown that for plain concrete it is impracticable to use fragments larger than will pass a 3-in. ring, and this only in very massive work. The more usual size is 2½ ins. For reinforced concrete 1¼ ins. is about the maximum size allowed, and in building work ¾ to 1 in. The great bulk of concrete work is done with aggregate smaller than 2 ins.,

and as a general thing, where the massiveness of the structure will allow of much larger sizes, it will be more economical to use rubble concrete. (See Art. 34.)

The size of the coarse aggregate should be proportioned to the sizes of the members in which the concrete is to be placed. The maximum size of the coarse aggregate should be such that it will not separate from the mortar in laying and will not prevent the concrete fully surrounding the reinforcement or filling all parts of the forms. In other words, the maximum size of aggregates is governed rather by the practical consideration of the size of structural members and reinforcement than by the requirement of strength or density of the mixture. (See page 423.)

Grading Aggregates.—In all cases a well-graded aggregate gives the best results; this means, not a mixture of two sizes of aggregate only, but a uniform gradation from the finest material up to the coarsest to be used, due attention being given to the effect of size of sand. In other words, the maximum strength of concrete will be secured for a given quantity of cement when the aggregates are so proportioned as to size as to reduce the percentage of voids in the mixture to a minimum. To reduce the proportion of voids to a minimum the aggregate should consist of particles of different sizes, so that the smaller will fill the interstices between the larger. This will be further discussed in Art. 13. A uniform size of coarse aggregate, filled with fine aggregate, does not make as dense or strong concrete as one in which the coarse aggregate consists of large and small stones so that the small stones may partly fill the larger interstices. An excess of medium sized particles of the aggregate decreases the density and also the strength of mortar or concrete.

Gravel vs. Broken Stone.—Many engineers have a decided preference for gravel over broken stone as an aggregate. Gravel is thought by many to be superior to broken stone in that the well-rounded pebbles, worn down as found in nature, are the survival of the best parts of the stone, the weaker portions having been worn away; also, that round fragments offer less surface to be coated, thus insuring better union with the mortar and giving, under similar conditions, a denser concrete than broken stone. On the other hand, the exponents of broken stone maintain that the rough surfaces and the angularity of broken fragments insure better union or bonding of the concrete. It has been demonstrated in all lines of work that equally good concrete can be made with either gravel or broken stone. It is generally found, however, that a wet gravel concrete can be handled much more cheaply than broken stone concrete. It dumps easily from cars or buckets, can be placed in the forms with little labor, and requires very little tamping. Wet gravel concrete will flow in chutes placed at an angle so flat that dry concrete or even a wet stone concrete will not move. (See page 104.)

Voids in Aggregates.—Both the sand and the aggregates employed for concrete contain voids. The amount of this void space depends upon a number of conditions (see page 133). As the task of proportioning concrete consists in so proportioning the several materials

that all void spaces are filled with finer material, the conditions influencing the proportion of voids in sand and aggregate must be known. In this connection, see Art. 13.

Care of Aggregates.—The principal care to be exercised in the handling of aggregates is to see that none is contaminated with dirt or foreign substances. Platforms should invariably be provided upon which all sand, gravel and broken stone may be placed when brought upon the line of the work, and kept there until used, and any not so placed should be rejected by the inspector. This precaution is especially important in street pavement work, for if sand, gravel or broken stone are deposited directly upon the earth, it is difficult to avoid taking up earth and mud with the materials, especially when the street is wet and muddy. In large operations, the aggregates are generally stored in open sheds or in covered bins. These storage places should have a wooden floor so that there will be no danger of shoveling up some of the soil and carrying it into the mixer.

In other words, after the aggregates are delivered at the site, keep them in separate piles and do not allow dirt from cart-wheels or horse dung to mingle with the aggregates. Of all things, do not allow street traffic to grind up and pulverize the sand and stone, mixing up with street sweepings to be shoveled back into the pile. *One shovelful of this kind of stuff occurring at a critical point of the work may cause a failure in reinforced concrete buildings.*

Concrete aggregates should also be protected from intense heat in summer and from freezing weather in winter. If the materials have been subjected to the heat of the sun, they are liable to cause trouble in the mixer by tending to cake the cement (see Art. 32). In the summer time, therefore, care should be taken to wet the stone down carefully (see page 164) and to protect the sand and broken stone or gravel from the heat.

In winter it is well to prevent the sand, broken stone or gravel from becoming wet and from having the moisture in them frozen, because frost is detrimental to the concrete (see Art. 33). When there are indications that the aggregates have been frozen, means should always be taken to thaw them out, either by forming a hollow in the material and building a fire therein, or by putting the material in a sheet-metal pan under which a fire is lighted. For other methods of heating aggregates, see page 356.

Use of Material without Screening.—If it is suitable for the purpose, material direct from the bank or crusher may be used without screening and subsequent mixture, but only with the permission of the engineer.

Washing Aggregate.—Impure sand or gravel may be used, provided the impurities be removed by washing to the satisfaction of the engineer. The washing for small jobs may be done in almost any type of batch concrete mixer by simply revolving the mixer and letting the hose play inside without stopping. When the mixer overflows, the water will carry off the foreign matter. For larger jobs, however, other arrangements should be made, subject to the approval of the engineer. In this connection, see page 103. Aggregates can be

cleaned by spreading them on an inclined platform, turning a hose on the pile, and allowing the water to carry the impurities.

Samples of Aggregate.—Samples of the sand, broken stone and gravel should be kept in the engineer's office as a standard for comparison during the progress of the work.

Sampling Aggregates.—Samples should be taken in such a way as to obtain a fair average of the material to be tested.

The size of the sample depends upon the character of the aggregate and the nature of the test. It is better to err on the side of getting too large a sample rather than one that is too small. For tensile or compressive tests of mortar made with sand or stone screenings (see page 101) a sample not less than 20 lbs. in weight should be taken, in order to have enough material left over for other laboratory tests that may be considered necessary. If practical tests of proportions with coarse aggregates are to be made (see pages 109 and 120), the sample of fine aggregate should be several times larger than this.

The coarse aggregate sample should be larger than that of the fine aggregate, in order to get fair average of the material, because the grains are larger and there is more variation in them. Whatever tests are made must be on a larger scale. For tests involving both sieve analysis (see page 147) and volumetric tests (see page 145) of concrete mixtures for proportioning the aggregates, at least 200 lbs. of each coarse aggregate are needed.

Samples should be shipped in a strong box or a bag. It is advisable that the natural moisture be retained as far as possible, so that the laboratory will receive the aggregate in its natural condition. For sub-dividing the sample to obtain the required amount for each test, different methods are used in different laboratories. One of the common methods is that of quartering.*

To quarter a sample of aggregate, it is spread out on a thoroughly clean floor or table, or else upon a large sheet of Manila paper. Care must be taken in spreading to see that particles of different size are distributed through the mass. The pile should preferably be in the shape of a circular disc. The aggregate in this shape is divided into four quarters. Two opposite quarters are removed, taking care to remove all dust. The remaining quarters are then mixed together. After mixing, the aggregate is spread out again, as before, and quartered again. This process should be followed until the quantity remaining is of the size required for the experiment.

Art. 8.—Sand, Crushed Stone and Gravel Screenings

Sand is used to fill the voids in the stone or gravel aggregate, and to reduce the amount of cement required. It constitutes from one-third to one-half of the volume of concrete. Natural sand is employed for the majority of concrete work, although fine crushed stone and gravel screenings are sometimes employed.

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*Committee of Natl. Assoc. Cement Users, Eng. Rec., Vol. 65, page 349, March 30, 1912.

Sand is an aggregation of loose, incoherent grains of a crystalline structure, derived from the disintegration of rocks. It is called "silicious," "argillaceous," or "calcareous," according to the character of the rock from which it is derived. Various kinds of rock are capable of producing sand of good quality. The natural sands are usually silicious in character, but calcareous sands are also met with and may give excellent results in concrete. The sand derived from the quartzose rocks is the most preferred for building purposes. Sand is obtained from pits or land deposits, banks and beds of rivers, the seashore, or may be made by grinding sandstones.

Pit or *bank sand* is that obtained from inland excavations. It has an angular grain and a somewhat rough surface, and often contains clay and organic matter. When washed and screened, it is a good sand for general purposes.

River sand is excavated along the shores or dredged from the bottom of bodies of fresh water. It is generally composed of rounded particles or grains, and may or may not contain clay or other impurities. River sand is commonly of fine grain and is often white in color.

Sea sand is excavated along the shores or dredged from the bottom of bodies of salt water. It contains alkaline salts that attract and retain moisture and cause efflorescence (see Art. 31). The grains are more or less rounded.

Durability of Sands.—As a rule, river and sea sands are more durable than glacial sands. The latter are rock-meal ground in the geological mill, and usually consist of silica with a considerable admixture of mica, hornblende, feldspar, carbonate of lime, etc. The silica is hard and durable, but the other constituents are soft and friable and are easily decomposed by the gases of the atmosphere and the acids of rain-water. Glacial sands frequently contain so large a proportion of soft and easily decomposed constituents as to render them unfit for use in exposed work, as, for example, in concrete sidewalks. Crushed granite is often used in the place of sand in concrete sidewalk construction; but granite frequently contains mica, hornblende and feldspar, which render it unsuitable for this kind of work (see page 466).

The river and sea sands are older geologically than glacial sands, and therefore are as a rule nearly pure quartz, since the action of the elements has eliminated the softer and more easily decomposed constituents. Some sea sands are nearly pure carbonate of lime, which is soft and friable, and therefore entirely unfit for use in mortar or concrete. These are known as calcareous sands.

Selection of Sand.—The proper selection of sand as one of the aggregates for concrete is largely a matter of judgment, as frequently, sands differing very materially in physical characteristics will make equally good concrete. Good sand cannot be easily defined, or an inflexible specification written, as sands of various properties may make equally as good concrete. The value of sand for concrete depends largely on its coarseness, graduation in size of the grains, and cleanliness. The best sand is that which, when mixed with cement and water in the required proportions by weight, produces the least

volume of mortar (see page 100). Care should be taken in the selection of sands to exclude all those which have come in contact with acid or alkali solutions. The selection of sand or fine aggregate is of as great importance as the selection of the cement. Indeed, if one does not know how to select either good cement or a good sand, he is in greater danger of going amiss in the selection of the latter than the former; for the cement has been placed upon the market by a manufacturer who has a reputation to establish or maintain.

Too little attention is given to the matter of sand and frequently one is allowed to be used which is absolutely unfit for the purpose, simply because there is no better to be had in the vicinity. Sometimes the proportion of cement is increased to offset the poor quality of the sand, but while this will in many cases help materially, there are many sands which are so bad that no amount of enriching will produce a good piece of work. A large percentage of unsatisfactory concrete is *due to poor sand alone.* Some sands are beautiful to look at, but as far as securing any amount of strength is considered they are absolutely worthless.

Inspection of Sand.—The inspection of sand will allow of neither neglect nor carelessness on the part of the inspector.

Specifications for Sand.—Specifications usually prescribe that the sand shall be "clean, sharp, coarse or large-grained, free from clay, loam and all other vegetable matters, and, if considered necessary, washed." However, it is not essential that the sand be sharp and angular or that it be absolutely clean. In fact, the phrase "clean, sharp sand," for so many years a stereotyped form in specifications, is now obsolete. Sharpness of sand is of little value except when it indicates the presence of silica (see page 94). Cleanness of sand is also disregarded by many engineers, who permit the presence of clay or of loam. Some authorities assert that in particular cases at least, and within certain limits, unwashed sand and the admixture up to a certain percentage of clayey material are positive advantages; the quantity allowed is from 2 to 10 per cent, some authorities allowing even 15 per cent. In rich mortars, clay or loam may prove detrimental; lean mortars may, however, be made more dense by a small percentage of clay or loam (see page 91). The inspector, however, must be governed by the requirements of the specifications; his duty is to determine whether the sand employed meets the requirements of the specifications and to see that only sand of the specified quality and character is used.

The author would prefer that all specifications should state that not over 5 per cent of clay or loam should be permitted in mortar or concrete for reinforced concrete work, as these impurities have a tendency to fill the small voids, preventing the cement from flowing in, and thereby reducing the adhesion between the cement and the aggregate, or the cement and the reinforcement.

GENERAL REQUIREMENTS

Pulverized or crushed stone, gravel screenings, powdered brick, slag, or coal cinders may be used as fine aggregate, provided it has

no effect upon the durability of the cementing material and is not itself liable to decay; but natural sand is by far the most common, although crushed stone and gravel screenings are often employed and are in some respects better than natural sand. Good sand and screenings being an important element in the making of a good concrete, the following characteristics should be required:

Quality of Sand.—The quality of sand used is only second in importance to the quality of the cement. It is the sand with which the cement comes in most intimate contact, and therefore upon the quality of the sand depends largely the efficiency of the cement. To be suitable for use in mortar or concrete, the sand should consist of grains of any moderately hard rock that is perfectly sound; that is, the grains should be composed of durable minerals. Any sand showing any indications of chemical decay should be unconditionally rejected. Sand should also be free from dirt, slime, vegetable matter and other evident impurities. However, it is not absolutely essential that the sand be perfectly clean. When acid or alkaline solutions are present in sand, the sand should not be used. The gradation of the sizes of the grains should be such as to give a minimum of voids, i. e., interstices between the grains, as mentioned on page 88.

Quicksand.—Do not use "quicksand" (sand that is worn round and very fine by the action of water) for making mortar or concrete. This sand is easily distinguished, as in the pile it is continually running down, thus making a very flat pile. Good coarse sand can be cut down in the pile with a perpendicular face, but this cannot be done with quicksand, as it slides like so many round balls. Quicksand may also be distinguished by its very small, round particles, some of the particles being almost a powder. When used in mortar, quicksand will settle to the bottom and the mortar has to be continually mixed or tempered. Sand of this kind will make a very weak mortar or concrete.

Sea Sand.—In doing concrete work with sand taken from the seashore, take care that the sand selected is secured from a point well above high tide and sufficiently far below the surface of the shore or beach to admit of the salt being filtered out. In other words, sea sand, if used, should be freed from salt, otherwise the salt will work out to the surface of the concrete and make a white stain; that is, the concrete will effloresce (see Art. 31), as sea sand contains alkaline salts that attract and retain moisture and cause efflorescence. This efflorescence is not at first apparent, but becomes more marked as time goes on. It can be removed, temporarily at least, by washing the surface in very dilute hydrochloric acid (see page 347). In marine construction this objection does not apply, and sea sand is almost invariably used. Salt does not affect the strength.

When sea sand is used for plastering or any work where the salt is liable to come to the surface and show, it should be thoroughly washed in fresh water. In fact, it is generally unwise to use sand from the seashore in concrete, unless it is first washed to free it from the salt. This regulation forms part of the government specifications for concrete work.

Sea sand should not be used in reinforced concrete, as it will cause corrosion of steel reinforcement, unless thoroughly washed.

Character or Mineral Composition.—The sand should be of hard, dense, tough material. It may consist of grains of almost any moderately hard rock that is not liable to future alteration in the work. Sands formed by the disintegration of soft rock, like slate, shale, or "rotten" stone, are not suitable. Sand should preferably consist of grains of silica, but a considerable proportion of other materials may be present without detriment. Silicious quartz sands are the most durable and unchangeable and give the best results, although sands ground down from any durable rock will answer. Sands which consist largely of grains of feldspar, mica, hornblende, etc., which will decompose upon prolonged exposure to the atmosphere, are less desirable than quartz, although after being made up into the mortar or concrete they are virtually protected against further decomposition. Mica is a very objectionable constituent, a small portion causing a serious reduction in the strength of mortar (see page 92). However, as a rule the physical condition of the sand is of more importance than its chemical composition.

A clean quartz or silica sand, if the grains are of suitable sizes, nearly always gives good results, but on the other hand, there are many really excellent sands which contain quite a considerable amount of hard limestone particles.

Sharpness or Shape of Grains.—The common requirement of "sharpness of grain" is unnecessary. By a sharp sand is meant one composed of rough, angular grains. Silicious bank sand is usually sharp; river and sea sands have rounded grains. In the past all specifications have called for clean, "sharp" sand, in spite of the fact that in many parts of the country where sharp sand is not obtainable, sand with rounded grains is furnished and used with perfect satisfaction. The shape of the grains of sand is of chief importance in the influence that the sand exerts on the percentage of voids. Obviously, a sand with rounded grains will compact into a more dense mass than one whose grains are angular or flat like particles of mica, thus giving a smaller percentage of voids. Therefore, the more nearly the grains approach the spherical in shape, the more dense and strong will be the concrete.

Contrary to common opinion, it has been proven by comparative laboratory tests, under conditions as nearly as possible identical, that sharpness in sands is not essential for good concrete, and that round grains give greater density and equal if not greater strength. In fact, the highest tests with cement have been obtained with sand having rounded grains with a dull surface. However, while the roundness of grain may exert a certain influence, it is of much less importance than the size of the grain.

In the event of selection between round or angular grains, preference should generally be given to the round-grained sand, as it packs more closely, affords no opportunity for bridging, and gives a minimum percentage of voids. Sand composed of round grains makes quite as strong mortar as does sand composed of angular or sharp

grains. This fact must be carefully remembered, as it is contrary to the common opinion on the subject.

Size of Sand.—Sand may be classed as coarse if it is retained on a sieve having 20 wires to the inch; it may be classed as fine if it passes through a sieve having 30 wires to the inch; and from 40 to 60 wires to the inch, very fine sand.

Grading Sand.—Sand may be hard and clean and still entirely unfit for use in concrete work of any kind. It should be well graded in size from coarse to fine,—from "pea" to "pin-point." Sands as they come from the pit, river or seashore are rarely graded properly, requiring either admixture of some coarser grades or separation out of some of the excessively fine material. Occasionally a sand will be found sufficiently well graded naturally, requiring no correction, but such deposits are extremely rare, and even the best deposits will be found to vary considerably as the excavation advances. The user will therefore need to be on the constant look-out and be prepared to make continual readjustment of his proportions. By a little mixing of the coarse and fine material one can soon determine what proportion of the two will give the densest mixture, and then the two materials can be mixed by measure in their natural state.

A sand composed of fine and coarse grains mixed is to be preferred, because less cement will be required to fill the voids; as between a coarse and a fine sand of one size of grains, the coarse sand is the better. In other words, to secure a minimum of voids, a mixed size of grain from fine to coarse should be used. Such a sand is better than one having grains of uniform size, and gives as great or greater strength than a coarse sand. The best graded sand is one in which the grains held on a uniform series of sieves (see page 101) are so arranged that the voids in one lot are filled, and not overfilled, by the grains in the next smaller size, and so on. Such a sand has the appearance of a very coarse sand, as the amount of fine material is small. The better the sand is graded, the less superficial area, and therefore the better it will be coated and the stronger the concrete it will make with a given quantity of cement. This grading should begin with large grains in order to limit the surfaces exposed to cement, and still these grains must not be so large that the voids will not be filled with the smaller particles. On the other hand, too many fine particles are undesirable.

It is very important that the sand be well graded, for upon the close packing of the grains depends largely the efficiency and economy of the mixture. The coarse grains should predominate. However, the sand should not contain an unreasonable amount of coarse particles.

Mesh Composition of Sand.—The largest grains should pass, when dry, a screen of ¼-in. mesh, and in such proportion that the voids, as determined by saturation (see page 99), should not exceed 33 per cent of the entire volume. At least 75 per cent of a sand should be retained on a 40-mesh sieve with the particles well distributed between that size and the size passing a 4-mesh sieve. No more than 4 per cent of fine aggregate should pass a sieve having 100 meshes per lineal inch. Such a sand will have much less total surface than

one sand made up entirely of fine particles and presenting a very much larger surface which must be covered with cement than either of the sands above mentioned. The total superficial surface of a given volume of spheres one-eighth of an inch in diameter is four times the surface of the same volume of spheres one-half an inch in diameter.

Some specifications require that the mesh composition of fine aggregate shall be such that at least 60 per cent, by weight, will pass a 20-mesh screen, not more than 85 per cent will pass a 50-mesh screen, and not more than 15 per cent will pass an 80-mesh screen.

Laws which govern the effect of the sizes of the particles of the aggregate upon the resulting mortar or cement are not yet clearly formulated.

Use of Fine Sand.—A sand containing more than 30 per cent of particles that will pass a No. 40 sieve is a fine sand and is generally undesirable, and should be avoided (it is difficult to mix evenly, and this usually leads to poor results). Fine sand, however, may be used alone, but it makes a weaker concrete than either coarse sand or coarse and fine sand mixed. In other words, fine sand produces a weaker concrete than coarse sand, but a mixture of fine and coarse sand will surpass either one, as mentioned in a previous paragraph. Such a sand should be used only after careful study of its behavior in mortar. A fine sand may show up well if the grains are well graded. Fine sand should never be used where concrete is to be laid in sea water. A very fine sand, or one containing an excessive amount of fine stuff, is highly undesirable, as it makes a weak concrete, and should therefore be avoided. If there is a large quantity of fine sand handy, get a coarse sand and mix the two sands together in equal parts; this mixture is as good as coarse sand alone.

If only fine sand is available, its weakness may be counteracted by the use of a large proportion of cement. A mortar consisting of very fine sand and the same cement will not be so dense as one of coarse sand and the same cement, although, when measured or weighed dry, both contained the same proportion of voids and solid matter. In a unit measure of fine sand there are more grains than in a unit measure of coarse sand, and therefore more cement will be required, as there are more points of contact. Fine sand requires more cement for a given strength and more thorough mixing. Objections to the use of a very fine sand may be stated as follows: (1) large percentage of voids in the material, requiring an excessive amount of cement as filler; (2) large surface to coat with cement, the amount increasing as the square of the size of grain, requiring an excessive amount of cement as binder; and (3) a crowding apart of the sand grains by the cement not being sufficiently larger than the cement grains themselves.

More water is required in gauging a mixture of fine sand and cement than in a mixture of coarse sand and the same cement, or in a mixture of coarse and fine sand. With very fine sand the water forms a film which separates the grains, thus producing a larger volume having less density.

Fine sand should not be used for concrete, even if it gives good results, unless there is coarse sand mixed with it. If very fine sand is the only kind available, the mixture must be excessively rich in cement, as mentioned above, and a smaller quantity of the sand in proportion to the broken stone or gravel may be used. The use of fine sand for concrete is deprecated where the concrete will be highly stressed.

Use of Coarse Sand.—Coarse sand is preferable to fine or mixed; the coarser, the better, if there is sufficient paste to fill the voids. The strength of the mortar depends upon the amount of paste. If less paste is used, a mixed sand is better than one composed of grains of uniform size, since the small grains will assist in filling the interstices or voids between the larger ones, and thus decrease the amount of paste necessary to make a homogeneous mass. A very coarse sand gives the greatest strength in concrete, but when the proportions of sand exceed 2 parts to 1 of cement, a sand of mixed grains, fine to coarse, with the coarse predominating, is preferable, as the fine sand helps to fill the voids in the coarse sand and makes a more dense and less absorbent mortar. In other words, coarse sand produces stronger mortar than fine sand, but to render concrete impermeable (see Art. 47) a certain amount of fine sand is necessary.

Coarse sand is preferable to fine, since (1) the former has a smaller surface area than a number of fine grains of equivalent volume, so that it will be better coated with fine sand, with the same quantity of cement; that is to say, coarse sand has less surface to be covered and hence requires less cement; and (2) the coarse sand requires less labor to fill the interstices with cement. For general work, however, a mixed sand is better than either, because of a better gradation of particles and a consequent lower percentage of voids. A coarse sand may show up poorly if there are too few fine particles to fill the voids. If a good coarse sand is not available, almost any size of sand may be employed, provided a sufficient proportion of cement is used as mentined for fine sand; though in this case tests should be made to see that the mortar or concrete sets and hardens properly.

Concrete made with coarse sand shrinks less than that made with fine sand.

A very coarse sand, or one containing an excessive amount of the maximum size grains, is very undesirable for the following reasons: (1) that it requires an excessive amount of cement, that is, it is "cement-hungry"; and (2) that it allows or requires the cement grains to be bunched together, thus decreasing their relative efficiency and therewith the strength.

Cleanness of Sand (Foreign Matter).—By a clean sand is meant one which, if shaken with water in a bottle and allowed to settle, will leave no scum on the surface of the water and no layer of fine mud on the surface of the sand (see page 95). In other words, by clean sand is meant that which is free from clay, loam, or foreign materials. River and sea sands, if not affected by the sewage of cities, are usually clean. The presence of dirt, organic loam, mica, etc., is decidedly injurious and tends to weaken the resulting concrete.

A good criterion of cleanness of sand is the freedom of its grains from sticking together. The sand may be coarse or fine, but if each grain admits of being wholly covered with a film of cement, the mortar will have the strength of the cement. If, however, several grains adhere together strongly enough so that they are not separated by the process of mixing the mortar or concrete, it is evident that the spot in the mass where this lump is will be no stronger than the lump itself. The material causing the sand to stick together may be clay, a film of silt, organic matter, oil or chemicals, but if effective enough to hold the grains together till the concrete is placed, it will cause a weak nucleus in the material.

The difference between clay and loam should be noted. Both are finely divided materials, but the clay is powder ground off rocks and boulders, and is thus naturally affinitive to both the sand and the cement, while the loam is a mixture of vegetable mold.

Some engineers require that sand shall not contain clay or loam to the extent of more than 1 per cent when used for reinforced concrete work, and shall be absolutely free from any other foreign matter. An addition of clay and (so-called) loam to sand, however, has been found in many instances to produce an actual increase in strength. The supposition is that it is because of the voids being more perfectly filled than if the sand were clean and sharp.

The contamination permissible in any particular case depends upon the cleanness of the sand available and upon the difficulty of obtaining perfectly clean sand. The permission to use sand with a small percentage of impurities is apt to be taken advantage of in a dangerous manner, for except where silica is present, loam consists largely of vegetable mold, which should be guarded against. The sand must be free from quicksand, mica, sticks, or organic matter and other impurities. These tend to retard the proper setting of the cement and destroy its adhesive quality. Under no circumstances should sand contain more than 2 per cent of perishable matter, nor enough clay or loam to render it unsuitable for the work. The sand may contain occasional pieces of small gravel. Sand containing mica should be rejected. Slimy sand is bad, for the ooze prevents the cement from coating the particles. When it is found necessary to use dirty sand, the strength of the concrete should be tested. Under no consideration should the sand contain many leaves, straw, paper, shavings, chips, etc. The sand may be moist, but not wet.

There is, however, another consideration, independent of the question of strength, that may decide a sand's fitness for the work at hand; namely, the surface finish required. Impurities in the sand, which may not impair the strength in the slightest, yet may produce unsightly discoloration of the surface, and therefore be unsuited for surface work (see Art. 39). No sand should be used for the outside finish of any concrete which contains small particles of coal or lignite, although sand of this character may be used in the interior portion of heavy pieces of concrete work.

Mineral or Inorganic Impurities.—Sand should not contain much inorganic earth of a soft mineral nature, such as silt or clay. Fine

mineral matter in small proportions may actually result in increased strength, but excessive quantities of silt or clay may be a possible source of weakness. If this foreign substance is in the shape of lumps, it is especially harmful, as these will make weak spots in the concrete. Lumps should be eliminated by sifting in preference to washing.

Some inorganic matter is very detrimental, for example, the strong chemicals from manufacturing plants which impregnate the water of many of our streams and rivers and render their water unfit to drink and uninhabitable for fish life. Sand from bottoms of streams into which chemical or manufacturing wastes are disposed are always open to doubt. Such sand is liable to be fouled and require, although seemingly clean, careful washing with fresh, clean water. Salt sea-bottom sands are also open to objection for a similar reason, the inevitable salt in this case probably being magnesium sulphate, which reacts injuriously with the cement (see page 62), causing it to swell and blow. The inspector should ascertain and report these facts to the engineer, for such sands need to be watched very carefully, as very many times failures of concrete structures scored against the cement are in reality due to the quality of the sand.

Silt up to 5 per cent will not, as a general rule, affect the strength of the resulting concrete, but the sand should not contain more than 10 per cent of silt, except where actual tests indicate that the sand proposed is as good as the average sand generally used in the locality where the work is being executed. The sand should preferably consist of less silt and of a combination of all sizes—not all fine or all coarse. An engineer should make briquettes of the different classes of sands on his work (see page 101), in order that he will be certain whether or not he is warranted in accepting sand with a slight excess of silt rather than a finer or poorly graded sand which comes well within the specifications as to silt. If the silt does not exceed 10 per cent of the whole mass and is not vegetable mold, the sand may be used (silt has been found to contain nearly 30 per cent of vegetable matter). If, however, sand is silty to any such extent, care must be taken that the work is cleaned every morning (see Art. 27), for if this is not done there will arise to the surface of each day's work a soft, slimy substance, which has no strength and which will form strata of demarcation between the successive courses. On waterproofing work, as a rule, a large percentage of silt is desirable, up to, say, about 15 per cent; but facing work should not, as a general rule, contain over 5 per cent, as the greater the amount of silt in the concrete, the greater amount of slime there will be carried to the face work.

Clay, if present, should be in a very finely divided condition. Where the clay is in lumps, it is impossible to obtain a good mixture without the most laborious and painstaking mixing process. A lump of clay means a weak spot. In other words, clay in lumps is very undesirable, for these lumps ball up the mixture, interfere with the coating of the particles with cement, and produce soft or "rotten"

spots in the concrete. Clay should not be permitted in sand for use in sea water. Good clean sand may be mixed with sand containing an undesirable amount of clay and the mixture made acceptable by this means. This would be preferable, in some cases, to washing and loosing the fine particles. If sand is ignited, clay will be broken up, and to some extent burnt, and thus rendered less harmful on account of being more durable.

Some time ago the author had occasion to examine some concrete work where the cement had been previously tested and accepted. It was at first difficult to understand why there were weak spots in numerous places in the work, as apparently all the materials were first-class and weather conditions were favorable. Finally a careful examination of the pile from which the sand was being used showed places where hard lumps of clay existed and the evidences were that these clay balls occurred in pockets in the sand pit. Afterwards a number of pieces of concrete were broken open and lumps of clay of appreciable size were found in almost every case. In this particular instance it would have been almost impossible to have obtained a suitable sand by any ordinary process of washing.

Mica is an objectionable element in sand, especially for surface work, as the little flakes float up to the top and cause the surface to dust and peel. Sand containing much mica is apt to be weak, as mica will not adhere well to the cement (see page 92).

Considerable difficulty has been experienced in certain parts of the country, especially in the oil regions, arising from the use of sand containing traces or small amounts of oil. Some time ago the author had occasion to examine sand from that locality and it seemed almost unnecessary to make any tests to determine its superior qualities. It was almost perfect as to gradation of sizes, apparently clean and in physical appearance, in fact, a most excellent material. On making up tensile tests, however, in comparison with Ottawa sand, the strength of the briquettes made from this sand and cement in the proportions of three parts of the former to one of the latter, was just about one-third that obtained from the Ottawa sand mentioned mixed in the same proportions with the same cement. It was finally discovered by chemical analysis that oil was present in the sand and while the amount was very small it was sufficient to prevent proper bonding of the materials. This was demonstrated also by extracting the oil from some of the sand and repeating the tensile tests, when a most excellent result was obtained. Unless one is on the lookout for this sort of thing it is easy to see how considerable work might be done before the trouble is discovered.

Vegetable or Organic Impurities.—Organic dirt is composed of vegetable matter in a state, generally, of decay. Loam is an example of organic dirt. Sand containing vegetable matter is of doubtful quality, as a small quantity may sometimes prevent hardening; even in amounts as small as 5 per cent, loam may prove detrimental. Vegetable matter will coat the grains of sand so as to prevent adhesion of the cement, and also retard the setting. Loamy sands, therefore, being used with cement, if used at all, will generally require

careful washing; or such sands should prove satisfactory by tests before using.

Dirt in sand should be viewed with suspicion. Natural sands are seldom found mixed with soil, unless it be for a small depth on top of the bed. The dirt may have been incorporated into the sand as a result of handling. Very often vegetable impurities in sand are washed down into the bank or pit from the soil above. Sand must be free from any kind of organic substance, such as roots, leaves and straw.

Color of Sand.—All sand used in concrete that will be exposed to view should be of a bright, uniform color. For most above-ground work, especially exteriors, the lighter the sand the better, and for architectural work a pure white sand is desirable. The selection on this score is thus one very largely of taste (see Art. 42, page 390). There are sands of all colors and shades, from the pure white sea sand to the blackish river sand and the reddish-brown bank or pit sand. The color of the sand makes less difference to the color of the finished concrete than might be supposed. This is due to the bleaching action of the cement, as mentioned on page 487.

While the color of a sand is important as it concerns the outward appearance, the desirability from a strength viewpoint may be, and generally is, in inverse ratio to the order of desirability as regards appearance.

The color of a sand is an indication, although by no means a conclusive one, of a sand's cleanliness (see page 97). A dark color in sand may be due to the presence of harmless iron salts. The determination of cleanliness will usually decide this point.

Artificial Sands or Screenings.—It has become the practice of late, in event of a suitable natural sand being unavailable, or requiring an inconvenient and expensive haul, to manufacture the sand to order, using the dust formed in crushing stone which passes through a sieve having 4 meshes to the lineal inch. Good artificial sand or screenings may be made from almost any kind of rock that is not liable to chemical decay, even though it be only moderately hard. These screenings will compare very favorably in grading with the best natural sands, containing, however, an excess of very fine material or dust. While screenings are frequently used as a substitute for sand, they are often mixed with the sand. In fact, the best results will usually follow the blending of an artificial sand with some natural sand, the same being both stronger and more impervious than either one alone.

Stone screenings, free from clay, constitutes a good material to use in place of sand. In fact, practically the only substitute for natural sand that is much used is pulverized stone, either the dust and fine screenings produced in crushing rock, or an artificial sand made by reducing suitable rocks to powder.

Gravel screenings usually makes excellent sand. The material is apt to grade quite coarse and to contain very little fine material, but the grains pack readily and the percentage of voids is not likely to be very high.

Coral sand (pulverized coral), found along the coast of Florida, has been used with satisfactory results.

Brick dust is a good substitute for natural sand.

Crushed marble is employed in the manufacture of some brands of artificial stone (see Art. 57). This may be mixed with cement alone.

"**Chats**" is another artificial sand considerably used in some parts of the country, notably the Joplin district, and other localities in the vicinity of lead and zinc mines. It is refuse from the concentration of the ores and often contains some mineral. Unless first very carefully examined, both physically and chemically, the use of "chats" should not be permitted. It frequently contains considerable sulphur in the form of sulphides which are liable to decompose from exposure to air and water, afterwards oxidizing and forming free acid. "Chats" from some places is shaly in character and when used in concrete gradually disintegrates and becomes soft. That, however, which is hard and flint-like and contains but traces of sulphur, often called "jig-sand," makes excellent material for the purpose.

For other materials suitable for screenings, see Art. 11.

An advantage of artificial sand or screenings is that the stone for it can be carefully selected, and that when crushed it will contain no injurious matter. The principal disadvantage is the liability to excessive dust, which would open the material to the same objections as to excessively fine sand mentioned on page 80. Very often, too, the dust will be segregated in pockets, which is, of course, highly objectionable.

Stone Screenings or Crusher Dust.—Crusher dust from broken stone may be substituted for a part or all of the sand, provided the product thus obtained passes the prescribed requirements for natural sand. By crusher dust is meant that portion of the product of the crusher which has been passed through a ¼-inch mesh. Screenings from broken stone must be from a hard rock, so they will contain very little dust. Trap, basalt, quartz and hard limestone make the best screenings, although good sandstones, granites and conglomerates make satisfactory screenings. Trap screenings will make the hardest and most durable, limestone the strongest and least permeable but less durable mortar or concrete. However, there is no objection to the use of limestone screenings for making mortar or for use in concrete, if the same rigid standard is maintained for them as is generally demanded of sand. There is as much variation in the quality of limestone screenings as in sand. In general, what applies to natural sand applies with equal force to screenings. A soft limestone will not furnish a good quality of screenings on account of dusting.

Tests frequently show a stronger concrete when stone screenings are used than when natural sand is used. In fact, the results of a large number of tests by different persons and different sands seem to show conclusively that stone screenings or crusher dust makes a stronger mortar than the best sand, the increase in strength some-

times reaching 100 per cent. In other words, stone screenings will often, if not in general, show higher strength than natural sands. This is perhaps due to the variable size of the screenings, which would have a less percentage of voids.

In regard to the use of stone screenings in place of sand, it is well to note that all dust must be screened out, and the screenings used should comply with the specifications for sand as to size of grains. Screenings are liable to contain an undue amount of dust, and hence it is very important that a sieve analysis of the material be made to determine the amount and the fineness of the dust present (see page 101). The dust is apt to ball up badly and prevent a good, thorough mixing. It also requires more water. Crusher dust containing particles of mica should be avoided. In passing upon stone screenings in lieu of sand look out for rotten dust. Rotten rock going through the crusher is, as a rule, crushed to dust.

Screenings from crushed stone containing all the dust of fracture should not be used as a substitute for sand, without the permission of the engineer. If the product of the crusher is delivered to the mixer so regularly that the amount of dust (as determined by frequently screening samples) is uniform, the screening may be omitted and the average percentage of dust allowed for in measuring the sand. If there is an undue amount of fine material or dust, the mass should be screened before being used in concrete. In using screenings, the aggregates should be carefully mixed dry, as otherwise the fine material will collect in lumps and impair the uniformity of the concrete.

Specific Gravity of Sand.—The specific gravity of silicious sands is quite uniformly 2.65; but glacial sand containing fragments of limestone, sandstone, shale and slate may have a specific gravity of 2.58, or even a little less. In fact, the specific gravity of sand ranges from 2.55 to 2.79. However, it is sufficient to assume the specific gravity of sand at 2.65, with little danger.

Weight of Sand.—The weight of sands is closely related with the question of their density, although it will vary also with the character of the native rock. Quartz sands are thus usually the heaviest, other things being equal. Dry sand weighs from 80 to 120 lbs. per cu. ft., or about one and a half tons per cu. yd.; moist sand, however, occupies more space and weighs less per cu. ft. or per cu. yd. From dealers' catalogues, bank sand is given as weighing 2,500 lbs. per cu. yd., and Torpedo sand, 3,000 lbs. per cu. yd. A common weight assumed for ordinary sand is 2,600 lbs. per cu. yd. Sand having very large and very small grains may weigh as much as 118 lbs. per cu. ft., or more than 3,000 lbs. per cu. yd.

Natural sands, to make good concrete, as they are, should weigh not less than 80 lbs. per cu. ft. in the condition that they come from the bank, and when dried and shaken, not less than 100 lbs. A 90 to 100 lbs. sand, moist and loose, or a 114 to 124 lbs. sand, dry and compact, would be still better.

According to Sabin's "Cement and Concrete," 1907 edition, page 184, natural sand as it ordinarily occurs will weigh about as follows:

Moist and loose	70 to 90 lbs. per cu. ft.
Moist and shaken	75 to 100 lbs. per cu. ft.
Dry and loose	75 to 105 lbs. per cu. ft.
Dry and shaken	90 to 125 lbs. per cu. ft.

Voids in Sand.—The voids present in a given mass of sand will depend upon (1) the shape of the grains, (2) the degree of uniformity in size of the grains, (3) the amount of moisture present, and (4) the amount of compacting to which the mass has been subjected. The two conditions exerting the greatest influence on the proportion of voids in sand are the size of the grains of which the sand is composed and the presence of moisture.

The more rounded the grains of a mixed granular material, the lower the percentage of voids. Natural sand, therefore, with rounded grains, gives the lowest percentage of voids of any material used as an aggregate (see page 71). Ground quartz comes next, then crushed shells, and finally crushed quartzite; the first having angular, the second, flat, and the third, laminated grains.

The finer the sand, the more nearly uniform the size of the grains, and, consequently, the greater the proportion of voids. The advantage of coarse sand over fine increases as the proportion of cement decreases, since with the smaller proportion of cement the voids are not filled. If the mass of sand consists of a mixture of two sizes of grains, such that the smaller grains can occupy the voids between the larger, then the proportion of voids may be very much smaller than with a single size of grains. The proportion of any particular size should be only sufficient to fill the voids between the grains of the next larger size. The smaller the proportion of voids, the less amount of cement required, and consequently the more economical the sand. In other words, the density of sand is a fair measure of its worth, since the best graded sand will invariably have the greatest density, or the least voids. The fitness of a sand may therefore be partially determined by ascertaining the percentage of voids, as mentioned on page 98.

Natural sands will always contain more or less moisture, so that in addition to the ordinary voids, such as the material would have if perfectly dry, therefore known as "air voids," there will be "moisture voids." In all aggregates used for concrete, except sand, the moistening of the material decreases the percentage of voids. This is because the addition of water destroys in part the arching or frictional effect, permitting the finer material to enter the voids of the larger material. With sand, however, dampness holds the particles apart and increases the percentage of voids, the maximum occurring when the percentage of water varies from 5 to 8 per cent. In other words, the percentage of water by weight which will give the greatest bulk, corresponding to the largest percentage of absolute voids, varies with different sands from 5 to 8 per cent, according to Taylor and Thompson's "Treatise on Concrete," 1909 edition, p. 177. The addition of more water, however, decreases the voids again, to somewhat less than that contained in dry sand. A dry, loose sand that has

45 per cent voids, if mixed with 5 per cent (by weight) of water, will swell, unless tamped, to such an extent that its voids may be 56 per cent. The same sand, if saturated with water until it becomes a thin paste, may show only 38 per cent voids after the sand has settled. The volume of sand is greatly affected by the presence of varying percentages of moisture in the sand.

The percentage of voids in sand will also depend upon the compactness. The degree of compacting of sand is largely dependent upon the percentage of moisture which it contains.

The percentage of voids in sand ranges from 25 to 50 per cent. The more uneven the grains in size, the smaller the percentage of voids. The percentage of voids in dry sand will range from 40 to 45 per cent for a very uniform sand to about 27 per cent for a coarse, well-graded natural sand. Generally the voids in ordinary good coarse sand will range from 25 to 35 per cent, but if otherwise suitable a greater percentage of voids would not be objectionable, provided a somewhat larger proportion of cement is used.

Tensile Strength.—Mortars composed of one part of Portland cement and three parts of fine aggregate, by weight, when made into briquettes (see page 44), should show a tensile strength of at least 70 per cent of the strength of 1:3 mortar of the same consistency made with the same cement and standard Ottawa sand (see page 101).

Care of Sand.—At the site the sand should not be laid in the dirt, as the last of it, when shoveled up, may contain an excessive amount of dirt and be the cause of a weak batch of concrete (see page 73).

Screening Sand.—The sand should be screened to remove the coarse gravel or pebbles, the fineness of the screen depending upon the kind of work in which the mortar is to be used. For use in concrete, screening is not necessary, but where the sand contains a considerable amount of such material, better and more uniform results will be secured by screening and remixing. For such purpose a ¼-in. screen is generally used, all material passing such sieve being considered as sand, or fine aggregate, and all material larger than this size being classed as coarse aggregate. For methods of screening sand, see page 102. Leaves, sticks, stones, etc., should be removed by screening.

Washing Sand.—When impurities occur, they may sometimes be removed by washing, but such work must be carefully inspected if the foreign matter be of a really dangerous character (see page 95). When the available sand carries considerable percentages of loam or clay and the specifications require that clean sand shall be used, washing is necessary. If the sand delivered on the work does not at all times conform to the degree of cleanliness required by the specifications, it should be washed for such length of time as may be necessary to render it acceptable. Sand for fine surfacings will in general require careful washing, in order to insure freedom from discoloration and uniformity in shade. Washing sand is worth all the trouble it takes, when the sand is dirty. For methods of washing sand, see page 103.

Washing does not always improve sand, as the finer particles

which may be of value to the compactness and solidity of the mortar are carried away in the process. The washing may remove all the impurities and also the finer sand grains, and thereby increase the per cent of voids, and hence weaken the mortar. In other words, washing is liable to take out the fine grains of sand, which are of great importance, as these fill the small voids and make the concrete dense and strong. That is to say, the fine grains, if not in excess, are needed to fill the voids of the larger. The only safe way to decide whether sand ought to be washed would be to test it under both conditions.

Rejection of Sand.—In all cases the engineer should decide as to whether any sand offered by the contractor shall be used on the work. At any time, however, if the sand, crushed stone or gravel screenings delivered does not fully meet the requirements as stated above, it should be immediately rejected.

Any sand or screenings showing signs of disintegration should be unconditionally rejected. Decayed particles of some kinds of stone, or grains which readily break up into thin scales, should be strenuously avoided. Sand or screenings containing over 5 per cent of mica or laminated particles may be rejected at the discretion of the engineer. Sand must not contain soft, friable or chalky particles; such sand should be entirely discarded. The best cement can form no adhesion to soft, yielding surfaces. Floury, powdery and dirty screenings should be at once condemned. Shale sand or shale dust should not be used.

If a sand is so fine that more than 10 per cent of the total dry weight passes a No. 100 sieve, that is, a sieve having 100 meshes to the linear inch, or if more than 35 per cent of the total dry weight passes a sieve having 50 meshes per lineal inch, it should be rejected or used with a large excess of cement.

The presence of any clay whatsoever may be sufficient ground for rejection. A loamy sand should not be used; it will give bad results and retard the set. Condemn sand for a noticeable quantity of mud balls, regardless of test (see page 82). In this connection an inspector should use some judgment as to the nature of the mud ball. Sometimes these mud balls are almost solid chunks of mud, and at other times they contain nearly all fine quartz, with very little mud.

Sand should be rejected which has come in contact with acid or alkali solutions.

Sand that will not absorb water should be avoided.

Sand containing over 45 per cent of voids should not be used to make mortars. Sands producing mortars having a strength of less than 70 per cent of standard Ottawa sand mortar (1:3) should be rejected.

EFFECT OF NATURAL IMPURITIES IN SAND

It is impossible to make a general statement either to the effect that natural impurities in sand are beneficial or that they are detrimental. In some cases fine material may be decidedly beneficial, acting as so much fine filler and therefore reducing the amount of cement required, or by helping to close up the pores, and thus

increasing the imperviousness, while in others the fine material may be decidedly objectionable. The case is covered by three conditions: (1) the character of the impurities; (2) the coarseness of the sand; and (3) the richness of the mortar.

Character of Impurities.—As to whether dirt in a sand is harmful or not depends upon the character of the dirt. The kind of impurity is really of more importance than the quantity. The presence of a small amount of clay in sand does not as a rule weaken or injure mortars or concretes, but it is generally considered that the presence of loam or dirt is objectionable. In other words, the sand should not contain such impurities as loam or humus, but for most purposes a small percentage of clay or fine rock dust is not objectionable.

Effect of Clay in Sand.—Fine particles of clay in sand, found naturally in the same and thoroughly mixed throughout the mass, do little or no harm. A small percentage of clay well distributed may be valuable for making the concrete work smooth, and especially for increasing its water-tightness (see page 430). In fact, one of the advantages of clay is it colloidal property, by which is meant its ability to puddle or merge, becoming impervious to moisture. It is this property of clay that makes it useful in earthen dam construction, in which in the form of a core wall it forms an effectual barrier to the passage of water. So, likewise, its presence in concrete mixtures, in proper amounts (see page 83), contributes to the water-tighness of the concrete and becomes thus, on occasion, a valuable adjunct.

The presence of the clay retards the setting of the cement—natural usually more than Portland—and makes the concrete more susceptible to the action of frost (see Art. 33).

The exact effect of the clay depends chiefly upon the fineness of the sand grains and upon the per cent of the voids in the clean sand. The benefit of clay in sand may be said in general to vary directly with the coarseness and amount of voids, that sand being the most benefited that is on the whole the coarsest and contains the most voids. In other words, clay is less harmful in coarse sand than in fine sand. It helps to fill the voids in coarse sand and causes the cementing material to coat the grains better and bind them more strongly, provided the clay is finely pulverized. On the other hand, a fine or well-graded sand would not profit—instead, likely be harmed.

The effect of clay in the sand varies with the richness of the mortar, i. e., with the proportion of cement. Lean mortars containing clay to a considerable per cent of the cement are more plastic and work better under the trowel than similar mortars made of clean sand. In some cases clay is added to produce this effect. The strength and density of neat cements and of mortars containing 1 or 2 parts of sand are decreased by even slight additions of clay; but the strength, and also the density, of mortars containing 3 or 4 parts of sand are usually increased by the addition of 10 to 15 per cent of finely pulverized clay, and still leaner mortars are improved by even larger percentages of clay. For rich mixtures, on the other

hand, even slight additions of clay may be detrimental, and setting may be seriously delayed.

The effect of clay depends also upon the thoroughness of mixing and the amount of water used, for if the clay forms a coating on the sand grains and is not removed in the mixing, or if the clay is in such condition as to "ball up" and stick together so as to remain in lumps in the finished concrete, a small amount of clay is very deleterious. It is only when the clay is in the finest kind of a powder, or, if moist, in a finely divided state, and thoroughly mixed through the mass, that it has a beneficial effect on the mortar or concrete.

Clay has been found by some experimenters to reduce the strength of mortar, and by others to increase it. The reason for this discrepancy is no doubt found in the difference in the nature of the clay. If the clay is added to the sand, the probabilities are that it will weaken the mortar, unless the clay is first finely ground or pulverized. If the clay is found in the sand naturally, it will probably add to the strength, because it is then more apt to be in a finely ground state.

The ultimate effect of the clay on the life of the concrete is a matter of doubt, even though short-time tests do show an increase of strength because of its presence.

No general conclusion may therefore be stated as to the desirability of clay, its presence or its absence being a matter for separate determination in each case. However, the author is of the opinion that clay should be regarded in general as a "necessary evil," to be tolerated on occasion but not condoned, certainly not licensed. Clay in limited quantities (say not to exceed 10 per cent) may be beneficial, if thoroughly distributed throughout the sand. Before using, however, it ought to be compared with an established standard.

Effect of Mica in Sand.—In many sections, mica is found mixed with sand in large enough quantity to interfere seriously with the strength of a mixture made from it. Its effect is more injurious upon fine sands than upon coarse. It greatly increases the amount of voids, and the smooth surfaces of the mica particles do not permit of a good bond with the surrounding cement. The presence of any considerable proportion of mica will destroy the value of any sand for concreting purposes.

Effect of Vegetable or Organic Impurities in Sand.—Sand containing vegetable loam shows up irregularly, frequently very detrimentally. Impurities of an organic nature have been found to prevent the concrete from hardening or to retard the hardening for so long a period as to make the sand entirely unfit for use. A very minute quantity of organic soil or vegetable matter may produce injury, so small a percentage, in fact, that frequently a sand which has passed careful inspection fails in practice to set properly with any brand of cement; therefore a test is absolutely necessary for any sand which has a suspicion of organic matter (see page 95). Vegetable or organic impurities are, as a rule, decidedly objectionable, and will require the washing of the sand.

Effect of Fine Material in Filling Voids.—Lean mortars may be improved by small admixtures of pulverized clay, as mentioned on page 91, or by substituting dirty for clean sand, provided it is free from vegetable or organic impurities, because the fine material increases the density or water-tightness. On the other hand, the richer the mixture, the greater the detrimental effect of foreign substances in the sand. That is to say, rich mortars do not require the addition of fine material, because the cement furnishes all the fine material required for maximum density. In many cases the addition of fine material to rich mortars may be positively detrimental.

Effect of Moisture upon the Volume and Weight of Sand.—The specific gravity of sand grains being nearly constant (see page 87), the weight of dry sand varies only as the percentage of void varies. Moist sand not packed weighs less than dry sand (see page 88), the difference depending upon the size of the sand grains and the amount of moisture. Ordinary moist sand contains 2 to 4 per cent of moisture and will weigh from 80 to 90 lbs. per cu. ft. in normally loose condition. Thoroughly tamping may easily reduce the volume and increase the weight 15 to 20 per cent.

DETERMINATIONS FOR SAND

Before commencing any considerable work, all available natural sands and possible substitutes, such as crushed stone and gravel screenings, should be examined to determine their fitness for use in concrete. The character of the sand employed is most important, since it vitally affects the strength, density and permanency of the finished structure. Frequently every carload of cement is carefully inspected and tested; but no test whatever, except by inspection, is made of the equally important ingredient, sand. Tests of the sand, unless it comes from a bank which has been previously tested, are as necessary as tests of the cement. The author will even go a step further, by saying that unless the sand is from a bank of *known quality* it is even more necessary to test the sand than to test the cement, for the cement has been placed upon the market by a manufacturer who has a reputation to establish or maintain, and greater chances can be taken. *Next to the cement, the sand is the important factor in determining the strength of the concrete.*

The impossibility of determining the true quality of a sand or other fine aggregates by mere inspection cannot be emphasized too strongly. *All sand must be tested.* When tests are made, they frequently are confined to sieve analysis or granulometric composition. While this is a valuable test for comparing the qualities of different fine aggregates that other tests have shown to contain no impurities, it does not show up some of the worst defects that occur occasionally. It therefore cannot be relied upon alone, but strength tests of mortars should also be made.

The usual determinations for sand are: Sharpness or shape of grains, fineness or size of grains, mineral composition, cleanliness or purity, weight, and amount of voids. These determinations elaborated and enlarged by specific gravity tests and strength tests of

mortars (tensile and compressive tests) constitute the usual laboratory investigations of sand or of fine aggregates. For the purpose of determining the relative value of a sand as regards the size of its particles, two methods are in use: (1) by separating the sand or fine aggregate into several sizes by means of sieves and determining the proportion of the various sizes (see page 101); and (2) by determining the proportion of voids in the sands or fine aggregate (see page 98. Sometimes fire-resistance tests are made for sand to be used in building construction. Very often all sand determinations are made in the works' laboratory, and the inspector has only to see that none but approved sand is used; but the inspector should be prepared to make at least approximate tests. In sampling the sand, care should always be taken to obtain an average sample. The following methods can be employed:

Sharpness or Shape of Grains.—The sharpness of sand can be determined approximately by rolling a few grains in the palm of the hand or between the fingers (applying considerable pressure) and noting whether there is any cutting action, or by crushing it near the ear and noting if a grating sound is produced. A few grains of sand rubbed between the thumb and finger will by its "feel" tell whether the grains are sharp or rounded; but an examination through a small lens is a better means. Sand which is otherwise acceptable should not be rejected for want of sharpness, as it has little to do with its value. Sharp sand is only of value as indicating a silicious sand. It has commonly been supposed that sand should be sharp (see page 78). This, however, is one of the theories which have been exploded. Strictly speaking, the grains of all natural sand are rounded rather than angular.

Fineness or Size of Grains.—The effective size of a sand cannot be determined by mere inspection, for sand which may appear to be coarse may contain so much fine material as to be in effect a fine sand. It seldom ever happens that a coarse sand contains too small an amount of fine material. The best method of determining the value of a sand with reference to its size is by means of a mechanical analysis made by passing a dried sample through a series of sieves and noting the percentages retained. The result of this test, expressed in the amount of sand passing each sieve, is known as the granulometric composition of the sand. This test cannot be relied upon fully, since there may be impurities in the sand that will make it unfit for use even when the analysis is satisfactory. The chemical and also the mineralogical composition of the sand also may affect its strength.

For analyzing sand, sieves with the following meshes are considered desirable: 10, 20, 30, 40, 50, 80, 100 and 200 meshes, respectively, to the linear inch. Fewer sieves will serve all the ordinary demands of field inspection; a No. 10, No. 20 and a No. 50 will give as complete an analysis as is usually necessary. Sand that is practically all retained on a No. 30 sieve is called coarse, while 75 to 85 per cent of sand known as fine will pass through this sieve. Material that does not pass a ¼-in. screen is not considered to be sand, and should be separated by screening. For screening out large

material from sand a screen with ¼-inch openings is generally employed.

Chemical and Mineral Composition.—Chemical tests are generally unnecessary, since sands may contain from 75 to 95 per cent of silica and still make first-class concrete. One of the most essential features of a good sand is that the grains should be perfectly sound. Evidences that chemical decay is going on in the grains would indicate that the sand is of very inferior quality.

The mineralogical composition of sand can be determined accurately only by laboratory analysis. It has but slight effect upon its combination with cement, and most authorities consider it of so much less importance than the physical properties that it may safely be passed without discussion, except to say that a sufficiently close determination for most purposes can be made by visual examination aided by a magnifying glass, by anyone reasonably familiar with the different rocks. Quartzite, which forms the bulk of the grains of silicious sands, is of a glassy appearance, while the visual determination of basalt, feldspar and mica is practically as easy.

Cleanness.—The cleanness of sand may be tested by rubbing a little of the dry sand in the palm of the hand, and after throwing it out noticing the amount of dust left on the hand. If the sand is dirty, it will badly discolor the palm of the hand. If the hand is nearly or quite clean after throwing the sand out, the sand is probably clean enough for concrete. The cleanness or purity of sand may also be roughly ascertained by pressing the sand between the fingers while it is damp and observing how much dirt adheres to them, and whether the sand sticks together. If the sand is clean it will not stick together, but will immediately fall apart when the pressure is removed. If the sand sticks together when the pressure is removed, it is entirely too dirty for use in concrete, and the character of the impurities should be investigated before finally rejecting it.

Taking a small amount of sand and examining it with a microscope will frequently show a crust of organic matter on the grains which is not readily brushed off.

Another simple test, besides the one of rubbing in the hand, is to throw a handful of the sand into water and let it stand for an hour or two. This will give a good idea of the amount of foreign matter in the sand. The presence of dirt in sand may also be determined by putting a handful of the sand in a small strainer and turning clean water on it, catching the water in a glass dish. After a while the dirt will settle in the bottom of the dish.

The cleanness of the sand may be tested quantitatively by shaking a sample of the sand in water in a slender bottle or a large test tube and allowing it to settle quietly, so as to approximate the amount of silt present. A graduated glass flask or bottle is preferable, as the amount of precipitate and of sand may be read from the graduation. If any impurities are present in the sand, they may separate from the sand on account of their lighter weight, or if in a very fine state of division, the water may be rendered murky in appearance. The percentage of impurities may be determined by comparing the depth

of the surface layer of mud with that of the clean sand. Care must be taken, however, that the precipitate has fully settled, since it will condense considerably after its upper surface is clearly marked. This test is not absolute, especially for calcareous sand, as the fine particles of limestone will give a murky appearance to the water, although not objectionable except on account of their extreme fineness.

The percentage of impurities may also be determined as follows: A small dried and weighed sample is placed in a vessel and stirred up with water. The sand is allowed to settle, the dirty water poured off, and the process repeated until the water pours off clear. The sand is then dried and weighed. The loss in weight gives the quantity of impurities contained in the sand. A modification of the above method is to place a weighed sample of sand in a glass beaker, add clean water, and stir vigorously; allow to settle for 15 or 20 seconds and decant off the water into a vessel; repeat the process until the water pours off clear; evaporate the water that has been decanted off and weigh the residue; divide the weight of the residue by the total weight of the sand put into the beaker and the result will be the percentage of impurities. The residue may be screened through a No. 100 mesh sieve to remove coarse particles which do not affect the strength, after the wash water has been evaporated. The silt passing this sieve is then weighed to obtain the percentage in the original sand, and then ignited in a platinum crucible to determine, after driving off the water, the percentage of combustible organic matter.

The following method of testing organic matter in sand is that given by Mr. W. J. Douglas:*

Wash a considerable quantity of sand, separate the silt from it, then make up a special sample from the sand and silt that has been separated, so that the latter sample will contain the maximum silt allowed under the specifications (see page 76). If the contractor is furnishing sands from more than one locality, it will be necessary for you to make the test herein described from samples of each of the localities, as will readily be seen from the nature of the test. Take the specially prepared sample just described and thoroughly mix the silt with the sand until the distribution is uniform. Then take a small portion of the proposed sample, about three thimblefuls (on my own work I have given the inspector an ordinary test tube, with a mark on the test tube indicating the height of the final sample of sand required.) Take this small sample of the prepared sand, drop it into a graduated beaker of clear water about 30 inches high, shake well until the sample has been thoroughly washed. Then take a domestic pin on the end of a wire or small stick and insert it in the top of the beaker, lowering it into the beaker until the pin is no longer visible from the top, and then read the position of the pin on the graduation at the side of the beaker. Make half a dozen similar tests, using the prepared sand, and the average of these samples will be the correct gauge for sand which does not contain over the stipulated amount of silt.

Of course, it is not necessary to sample every carload or barge of

*_Engineering News_, Vol. 56, page 648, December 20, 1906.

sand that comes in, as the bulk of it can be determined by superficial observation. If you are in doubt, however, take a number of shovelfuls of sand from various parts of the car or barge, mix thoroughly and take out the necessary amount of sand for test. Drop same into the beaker, shake, lower the pin, read the gauge. If the pin is then lower than the gauge, the sand has less silt than the maximum; if it is higher, it has more silt. If you use this method, it will take about an hour to get your first sample prepared and your gauge determined, after which two or three minutes will enable you to make the test.

The color of sand is an indication, although by no means a conclusive one, of the sand's cleanliness. In any case, what causes the color should be ascertained, the sand tried with cement to determine its effect on the setting qualities and tensile strength, and the treatment decided accordingly. As to whether coloring matter present in a sand is harmful will of course depend largely on what it is. If of mineral nature or insoluble, it will in general be harmless; if vegetable or soluble, the reverse. If the color is due to harmful dirt, it may be easily detected by rubbing a sample of the sand against the palm of the hand. A dirty stain, probably odorous, indicates undesirable matter. The color may also be shown by stirring some of the sand in a glass of clean water—muddy discoloration being the sign. A yellowish turbulence, however, may only indicate clay.

To Determine the Presence of Salt.—The presence of salts in sand may be determined by adding nitric acid and nitrate of silver to a sample of the sand previously allowed to settle in pure distilled water. A small portion of the sand should be well shaken up with distilled water in a perfectly clean stoppered bottle. After the sand has been allowed to settle, add a few drops of pure nitric acid and then add a few drops of solution of nitrate of silver. A white precipitate indicates a tolerable amount of salt; a faint cloudiness may be disregarded.

To Determine the Presence of Clay.—The presence of clay may be determined by permitting a small quantity of the sand to settle in water. The clay, if present, will separate in a distinct layer. That is to say, the sand and clay will separate into two well-defined layers, after allowing the sample to settle for two or three hours.

Absorption.—Sand is sometimes tested for absorption. This cannot be accomplished in the manner of usual percentage tests, as the capillary attraction between grains will take up a considerable amount of water, even though the sand be practically non-absorbent. The proper way is to let the sand soak for an hour or so, and then examine it. A sand which shows the slightest tendency to dissolve or soften under such treatment should be discarded.

Washed vs. Unwashed Sand.—Before accepting sand containing a large percentage of foreign matter tests should be made of that particular sand washed and unwashed, so as to determine whether the dirt present is actually baneful before undertaking to wash. In other words, sand should be tested, washed and unwashed, to determine whether washing is profitable.

Weight.—The weight of sand is determined by merely filling a

cubic-foot measure with dried sand and obtaining its weight. Weight tests are desirable but will vary considerably with the percentage of moisture present. The weight of sand is more or less dependent on its specific gravity and on the size and shape of the sand grains. The chief factor in the weight, however, is the proportion of voids. The less the percentage of voids, the heavier the sand, and other things being equal, the heaviest sand makes the best mortar. In other words, the weight of a sand, being a measure of the voids, is a good indication of the value of a sand, that sand being in general the most suitable which is the heaviest. The weight property may be made the basis of a table by which, knowing the weight, the voids can be at once read off, thus saving the bother of a separate determination, or conversely, knowing the voids, the weight per cu. ft. can be seen.

An easy method of judging of the value of different mixtures of aggregates is to dry a little more than a cubic foot of each and then fill with each a box made exactly 12 in. square and 12 in. deep inside, and accurately weighing (first weighing the box to get the net weight). That mixture which weighs the most will as a rule produce the strongest concrete with a given proportion of cement.

Specific Gravity.—The specific gravity of sand is found by a method similar to that used for finding the specific gravity of cement (see Art. 5, page 51). The specific gravity of sand ranges from 2.55 to 2.79. For all practical purposes, the specific gravity may be assumed to be 2.65 with little danger of error.

Determinations for Voids.—The determination of voids is very important, not alone as a means of ascertaining the fitness of a sand, but in order to adjust the proportion of cement required. There must evidently be enough cement to fill all the voids in the sand. As before stated (see page 79), a mortar is strongest when composed of fine and coarse grains of sand mixed in such proportion that the percentage of voids shall be the least. By percentage of voids is meant the amount of air space in the sand. Structurally, it is one of the most important properties of sand. The greater these voids, the more cement paste will be required to fill them in order to get a dense mortar; or, conversely, with a given proportion of cement and sand, the sand that has the smallest voids will produce the strongest, the densest, and the most impervious mortar.

The simplest method of comparing two sands is to weigh a certain gross volume of each as mentioned on page 97, the sand having been thoroughly shaken down. Assuming that the stone itself of each kind of sand has the same density, then the heavier volume of sand will have the least percentage of voids. The actual percentage of voids in sand may be determined by either of two methods, which for brevity will here be designated as (1) determining voids by the specific gravity method; and (2) determining voids by direct measurement. The first method, if the specific gravity of the sand is known or can be readily determined, is to weigh a given bulk of the sand, loose or compacted as required, correct for moisture, and compute the voids directly. In the second method, the percentage

of voids is determined by observing the quantity of water that can be introduced into a vessel filled with sand. The percentage of voids is best computed from the specific gravity and the weight per cubic foot of the sand to be tested. While void tests are desirable, they will vary considerably with the percentage of moisture present.

Determining Voids by Specific Gravity Method.—This method consists in determining (1) the specific gravity of the sand (see page 87) and from that computing the weight of a cubic unit of the solid material, and (2) the weight of a cubic unit of the sand. The difference between the first weight and the second weight, divided by the first weight, gives the proportion of voids, or expressed in percentages, gives the per cent of voids. The weight per cu. ft. of sand containing no voids at all is evidently equal to the product of its specific gravity times 62.5 or the weight of water per cu. ft. Nearly all materials of which sand is composed have a specific gravity between 2.6 and 2.7. The specific gravity of quartz is 2.65, hence a solid block of one cubic foot would weigh about 165 lbs. The voids in quartz sand may be calculated from the weight per cu. ft. by noting the per cent that it falls short of 165. The percentage of voids in a sand may be expressed by a formula as follows:

$$\text{Percentage of voids} = 100\frac{62.5 \times \text{specific gravity}}{100 \times \text{weight per cu. ft.}}.$$

Assuming a specific gravity of 2.65; let W=weight of the dry sand, V = absolute volume of the solid material, and P percentage of voids; then $V=W/(62.5\times2.65)=W/166$ and $P=100\ (1-W/166)$.

Example.— What is the percentage of voids in a sand having a specific gravity of 2.65 and weighing 105 pounds per cubic foot? Solution.—$P=100(1-105/166)=100-63.4=36.6$. Ans.—Pure sand weighing 100 lbs. per cu. ft. has close to 40 per cent of voids.

The sand should be dried at a temperature not less than 212° F. until there is no further loss of weight. However, the space occupied by the moisture in the sand can be found, if desired, by first weighing the moist sand and then the dry sand. The difference is the weight of the water, from which its volume is found. The volume of sand is much affected by moisture and by its degree of compactness so that for accurate comparative purposes the sand should be thoroughly dry before measuring as mentioned above and definite methods of compacting employed. The weight of a unit of sand may be determined for the sand loose, shaken, or rammed, and the per cent of voids will be for the corresponding condition. Generally the voids are determined with reference to the dry material well shaken. However, some authorities are of the opinion that it is better to determine the voids for the sand when rammed, since the mortar is either compressed or rammed when used.

Determining Voids by Direct Measurement.—The proportion of voids may be determined by filling a vessel with sand and then determining the amount of water that can be poured into the vessel with the sand. The quantity of water poured into the sand divided by the amount of water alone which the vessel will contain is the proportion

of voids in the sand. The quantities of water as above may be determined either by volume or by weight. The percentage of voids may be determined for the sand loose, shaken, or rammed, as mentioned above for weighing sand. For accurate work the sand should be thoroughly dried, in order to expel all moisture, as moisture affects both the weight and the volume of the sand, particularly if the sand is fine. Even if the sand is so coarse that its volume is not appreciably affected by the moisture present, the sand should be thoroughly dried, since it is the total percentage of voids in the sand, and not of the air-filled voids alone, that is desired.

The above method of pouring water into sand is subject to considerable error, since it is quite certain that air will remain in the voids in the sand, which will not be dislodged by the water, particularly if the sand is fine or has been rammed, and the apparent volume of voids will be less than the actual. In other words, pouring water into sand gives unreliable results, as the air cannot easily be driven out of the sand to admit the water, especially if the sand is dirty, as there is liability of the dirt being washed down and forming a stratum which will prevent the water from penetrating to the bottom. If the air is not driven out, or if the water does not penetrate to the bottom, the result obtained is less than the true percentage of voids.

Hence, to determine the voids more accurately, a known volume of sand should be dropped into a measuring vessel containing water. The volume displaced by the sand, subtracted from the original volume of the sand, will give the volume of voids. Or, the quantity of water in the vessel with the sand, divided by the amount of water alone which the vessel will contain, is the percentage of voids in the sand. Part of the water should be put into the measuring vessel and the sand slowly sprinkled into the water, so as to give the air bubbles an opportunity to escape. The sand should not drop through any considerable depth of water, as there is a likelihood that the sand may become separated into strata having a single size of grains in each, in which case the voids will be greater than if the several sizes were thoroughly mixed. Add water from time to time, and continue to drop in the sand until the vessel is full of water and the sand is at the top of the water. The proportion of voids is then found by dividing the quantity of water in the vessel with the sand by the amount of water alone which the vessel will contain.

The precise determination of the percentage of voids in a sand involves the measurement of the specific gravity of the stone of which the sand is composed, and the percentage of moisture in the sand, all of which must be done with elaborate precautions as mentioned on page 99.

Volumetric Synthesis.—When several sands are available that which will give the strongest mortar may be readily determined by drying a quantity of each and then weighing out 10 pounds of each and mixing with a given weight of cement, say, 4 or 5 pounds, using the same quantity of water with each batch. Then turn the different batches into boxes or tubes of the same size. That batch which when

set makes the least volume will make the strongest and least permeable mortar. The same process may also be used with broken stone or gravel, as described on page 109.

Sieve Analysis.—The most accurate method of determining the value of a sand with reference to its size is by means of a sieve analysis. This consists of shifting the sand through several different sieves, and then plotting upon a diagram the percentage by weight which is passed (or retained) by each sieve—abscissae representing size and ordinates representing percentage. The curves thus plotted on cross-section paper indicate the percentages of the whole mass that pass the several sieves. A straight line indicates a uniform grading of size. (See page 147.)

A standard size of sieve is 8 in. in diameter and 2¼ in. high. Woven brass wire sieves are employed for openings less than 1/10 in. in diameter; while for larger openings sheet brass is used, having circular openings drilled to the required dimensions. The woven brass wire sieves are given commercial numbers which approximately coincide with the number of meshes to the linear inch. The actual size of hole, however, varies with the gauge of wire used by different manufacturers, and every set of sieves must be calibrated separately. A common defect in sieves is the displacing of the wires so that they are not perpendicular to each other; such sieves should be discarded. Sieves are made to fit together in nests, so that when a sample of sand is placed in the upper (or coarsest) sieve and the nest of sieves is thoroughly shaken, the quantity caught on each sieve can be determined at once. For analyzing the sand the following sizes are desirable:

Commercial No.	10	20	30	40	50	80	100	200
Approximate size of hole in inches	0.073	.034	.022	.015	.011	.007	.0055	.0026

A screen with ¼-in. openings is generally employed for separating out large material from sand.

Tensile or Compressive Test of Mortar.—The test of the strength of mortar is the best for indicating the quality of the fine aggregate. In fact, it is advisable, prior to the selection of a sand to determine what its strength will be when made into mortar. The value of a sand cannot always be judged from its appearance, and tests of the mortar prepared with the cement and the sand proposed, should always be made for reinforced concrete structures. Sands that appear excellent are sometimes incorporated into the work, with the result that a weak and soft mortar is obtained, thereby causing the loss of considerable time. For tensile or compressive tests of mortar made with fine aggregate a sample not less than 20 lbs. in weight should be taken in order to have enough material left over for other laboratory tests that may be deemed necessary.

To eliminate variations in result, due to the character of the cement, the difference in laboratory conditions, and the personal equation of the operator, the test should always be a comparative one. For comparison, standard Ottawa, Ill., sand, which is used for cement tests (see Art. 5, page 57), should be used. This sand is recom-

mended by the Committee of the Am. Soc. C. E., and should be screened to size by means of a No. 20 and a No. 30 sieve. The percentage of voids of this sand is about 37 per cent. The grains are rounded and it is readily compacted. Other sands of smaller grain or larger percentage of voids are likely to give somewhat lower results in mortar tests.

Sand used in reinforced concrete should be accepted only after tensile or compressive tests of 1:3 mortar made with the sand in question as recommended by a Committee of the National Association of Cement Users,* in comparison with similar tests of mortar of standard sand made up at the same time under the same conditions.

To avoid the removal of any coating on the grains which may affect the strength, bank sand should not be dried before being made into mortar, but should contain natural moisture. The percentage of moisture to use for correcting the weights in measuring the proportions may be determined upon a separate sample. From 10 to 40 per cent more water may be required in mixing bank sands or artificial sands than for standard Ottawa sand (according to the above committee) to produce the same consistency.

In the mortar tests, enough specimens should be made to test at 3 days, 7 days, and 28 days, the first 24 hours of all specimens being in moist air, maintained at a temperature of 70° F., and the remainder of the period in water at the same temperature. The 3-day test is the most severe, and sand failing to attain this requirement frequently reaches it at 7 days or at 28 days, and can then be accepted. If, however, the 3-day briquettes break in the clips of the machine or if the specimens at this age show very low strength, say 25 per cent or less, of the strength of standard sand mortar, the sand should be considered dangerous to use on any important work of construction.

Mortar tests may be made at intervals of 7 days, 28 days and three months with sand both in its natural state and after washing. If the natural sand gives higher tensile strength, washing can be dispensed with. These tests are simply for the purpose of determining whether it is advisable or not to wash the sand.

Where water-tight work is required, the more elaborate granularmetric analysis may be used if the supply of sand is uniform in character (see page 101).

PREPARATION OF SAND

Sand is prepared for use by (1) Screening, (2) Washing, if necessary, and (3) Drying, if necessary.

Screening.—Sand is prepared for use by screening to remove the pebbles and coarser grains. The three most common methods of screening are (1) by hand, that is, by throwing shovelfuls of the sand onto an inclined screen, (2) by dumping or hoisting the sand onto a fixed incline screen, (3) by a revolving screen. The fineness of the meshes of the screen depends upon the kind of work in which the sand is to be used.

**Engineering Record*, Vol. 65, page 349, March 30, 1912.

Washing.—Sand is cleansed by washing with water, either in machines designed especially for the purpose, or in boxes furnished with holes to permit the dirty water to flow away. Sand cannot be washed simply by wetting the pile of sand with a hose as is sometimes supposed, for this only washes or transfers the dirt to a lower part of the pile. When only comparatively small quantities of clean sand are required, it can be washed in a box, not too tight at the bottom, and the water run through the mass until it comes out clean. Small quantities of sand may also be washed by shoveling it into the upper end of an inclined V-shaped trough and playing upon it with a hose, the clay and lighter organic matter floating away and leaving the clean sand in the lower portion of the trough, from which it can be drawn off by removing plugs in the sides of the trough. The washing may be done by the use of an inclined trough with a gate at the lower end. Sand is placed at the high end as in the case of the V-shaped trough and played upon with a hose. The clean sand settles at the low end of the trough, and the dirty water flows over the gate.

Sand may also be washed by placing it on a screen and playing upon it with a hose, or by placing it in an inclined revolving cylindrical screen and drenching it with water. The most satisfactory plan for washing appears to be to wash the sand down a trough over screens in the bottom of the trough, or against and through screens inclined in the opposite direction from the trough. For sands a screen with 30 meshes to the linear inch is necessary to prevent the good particles from passing through it. The screen must be supported by cleats placed quite near together, or it will break through. The sand is shoveled on the upper end of the trough by one man, while another one can wash it with a hose. The flow of water will wash the sand down the inclined trough, and as the sand and water pass over the screen the dirty water will drain off through the screen, leaving the clean sand for use. By this arrangement the dirt which is washed out cannot in any way get mixed with the clean sand as in the case of the inclined V-shaped trough with screens. It will be found that screens with round punched holes are better for this purpose than wire mesh.

Concrete mixers may be used for washing sand, the sand being dumped into the machine in the usual manner. Water is then turned on, and when it overflows at the discharge end the machine is started. The dirt is separated from the sand by this operation, and is carried off by the overflow water. The sand is dumped in the usual manner, after the water runs clear enough to indicate that the washing is sufficient.

Sand can also be cleaned by spreading it on an inclined platform in a layer 3 or 4 inches deep, and washing gently with a ¾-inch hose from the high end of the platform. Pieces of board projecting up about 4 inches above the face of the platform, should be nailed around its edges to confine the sand, the water being allowed to flow over the top of the board nailed across the low end.

Drying.—When dry sand is required it may be obtained by evaporating the moisture either in a machine called a sand-dryer, or by

heating the sand in large shallow pans of wrought iron or on sheets of boiler-plate supported on stones with a wood fire placed underneath. For other methods of drying sand, see Art. 33, page 356. Too high a temperature will cause sand to turn red.

Art. 9.—Gravel for Concrete

Gravel consists of pebbles which vary in size from a small pea to a walnut or sometimes larger, produced from stones which have been broken up and then worn smooth with rounded corners. It is often intermingled with other substances, such as sand, loam, clay, etc., from each of which it derives a distinctive name. The term "gravel" is sometimes used as meaning a mixture of coarse pebbles and sand, and sometimes as meaning pebbles without sand. The first definition is the more logical and also the more common, and will be used in this volume. Much that has been said about sand in Art. 8 is true of gravel except that sand is in a sense more important than gravel. Screened gravel constitutes generally a satisfactory coarse aggregate.

Joplin gravel, or the grits from lead mines, makes good material for use in concrete. In this connection see page 86.

Shingle is the small stones found on the shores of rivers or the sea.

Grit is fine gravel, the pebbles of which do not exceed one-half inch in diameter. The name grit is also applied to hard sandstone.

Crushed gravel is sometimes used in concrete. This is a very good material, if the gravel is a good, clean variety.

Durability of Gravel.—Practically all that was said about the durability of sand on page 75 applies with equal force to gravel. Most gravels are sufficiently durable for use in concrete. The very fact that they have been exposed for indefinite periods to atmospheric disintegration and mechanical wear, is generally a proof of the durability and mechanical strength of the stone. From the standpoint of durability, gravel must be superior to stone for the reason that, by the laws of the survival of the fittest and by process of elimination, nature has supplied us with the most durable. Sandstone pebbles are not considered as good as the better grades of broken stone (see Art. 10). The quartz pebbles are harder, stronger, and less liable to fracture.

Gravel vs. Broken Stone.—In some cases gravel is preferable to broken stone as so many stones have a flaky cleavage and the rounded pebbles make a more even and sounder or denser concrete than these flaky pieces, owing to the ease with which the sand and cement can fill the voids. In other words, the roundness of the pebbles lends aid to compactness, and the gravel is not likely to bridge and leave holes in the concrete. Gravel is usually found graded from coarse to fine. The chief argument against gravel is that the mortar is not supposed to adhere as well to the surface as that of freshly broken stone. This is one of the theories which is practically due to the appearance of the surface to the eye or touch, for the adhesion of mortar to limestone of a smooth surface may be much greater than to sandstone or rougher materials. If roughness were the only re-

quirement for adhesion it would seem impossible to cement together two pieces of glass. For a further discussion on gravel vs. broken stone, see page 72.

Gravel-Broken Stone Combination.—A mixture of gravel and broken stone gives excellent results. In this case the concrete proper is really based upon the gravel, which assists in compacting the mass, and the broken stone is "bulk-sweller" only. A mixture of this kind also leaves but a small percentage of voids in the mass, thus decreasing the amount of mortar required. Tests show that such a mixture gives both a stronger and a denser concrete than either gravel or broken stone alone. This may be attributed to the irregular and large pieces of broken stone acting as reinforcement so to speak, interlocking the mass in every direction, and the greater density being due to the sealing of all connecting passages in the sand and gravel by the uniformly distributed pieces of broken stone.

GENERAL REQUIREMENTS

The same general rules used in the selection of a good grade of sand (see page 76) will apply to gravel.

Quality of Gravel.—To be suitable for use in making concrete, gravel should be composed of reasonably clean pebbles of hard and durable stone of such a variety of sizes as to give a small per cent of voids.

Sea gravel will cause corrosion of steel reinforcement in concrete mixed with it, and should therefore be washed before using.

Mineral Composition.—Gravel sometimes contains proportions of soft stone-like shale, and, if there is a noticeable amount of such stuff present the material is unsuited for use until separated out. In other words, gravel may contain particles of soft, friable material which will seriously reduce the strength of the concrete. In fact, some failures of concrete have been attributed to the free use of gravel containing such material. In some localities, particularly in the foot-hills of the Appalachian and the Ozark Mountains, a material, locally called gravel, composed of angular fragments of chert, is found in the stream beds; but such material is unsuitable for concrete, since it is checked and is easily broken.

Sizes of Gravel.—A good gravel for concrete should be of varying sizes wherein the sizes of the pebbles range downward from say 2½ inches to ¼ inch. In columns, slabs and small beams the maximum size of the gravel should not run over 1 inch, preferably not over ¾ inch, and in members of larger proportions 1¼-inch gravel may be used and in massive work 2-inch gravel.

Grading Gravel.—A gradation of sizes of the pebbles should invariably be insisted upon. The proportions of sizes should be such that there is approximately 50 per cent of each size with reference to the next largest. Concrete made of such materials will be homogeneous, dense, and of great strength. Graded gravel contains a smaller percentage of voids than broken stone.

Cleanness of Gravel.—Gravel should be watched very carefully for foreign materials, such as lumps of clay from stripping the hard pan strata, sticks, decayed matter, etc. What has been said of cleanliness in regard to sand applies with equal force to gravel. Material that is really foreign, such as vegetable mold or loam, will be detrimental to the strength of the concrete.

The gravel should be clean and free from dust, dirt and other foreign substances, and washing of same should be required when considered necessary by the engineer, in order to render it sufficiently clean. Gravel is apt to be mixed with dirt, either in the form of lumps of coal or of slimy covering on the pebbles, or as in the case of sand, in the form of an admixture of clay, mud or silt. Such gravel should be washed or rejected, as silt or loam forms a film which reduces the strength of the concrete. If from the bed of foul streams, or from a loamy bank, it will need washing. In other words, gravel should be composed of clean pebbles, free from sticks and other foreign matter, and containing no clay or other material adhering to the pebbles in such quantity that it cannot be lightly brushed off with the hand or removed by dipping in water. That is to say, the gravel should be reasonably clean and ready to mix into concrete when unloaded from the wagons. A loss of 15 or 20 per cent in the strength may be caused by the use of a dirty gravel.

So-called yellow gravel is not necessarily a sign of weakness, although such a deposit should be carefully examined. Many times such a surface discoloration is caused by leechings from deposits or strata of oxide of iron or other minerals.

When containing sand in any considerable quantity the amount per unit of volume of gravel should be determined accurately to admit of the proper proportion of sand being maintained in the concrete mixture.

Clay in Gravel.—The presence of a small amount of clay in gravel, possibly as much as 10 per cent, does not as a rule weaken or injure the concrete for many uses, and may add to the strength of the concrete, particularly if the cement paste does not entirely fill the voids. The clay should be in a granulated or finely divided form and not adhering to the pebbles, for if the surface of a pebble is smeared with clay, the mortar will not be able to adhere as well to that surface.

Voids in Gravel.—All that was said about voids in sand (see page 88) applies with equal force to gravel. Since the particles are larger in gravel than in sand, the former may have, and usually does have, a smaller percentage of voids. The percentage of voids is usually less in gravel than in broken stone. It is rare that gravel has less than 20 per cent or more than 45 per cent voids. If the pebbles vary considerably in size so that the small fit in between the large, the voids may be as low as 20 per cent, but if the pebbles are tolerably uniform in size the voids may approach 45 per cent. The voids of a well-proportioned gravel passing a 2-inch screen usually range from 20 to 30 per cent.

Coarse gravel is sometimes run through a crusher to reduce the size of the larger pebbles, after which the material has a larger per

cent of voids, because the sharp angles of the crushed gravel prevent it from packing so closely.

Specific Gravity.—The specific gravity of gravel is practically constant and equal to 2.65, the same as for sand.

Weight of Gravel.—The weight of gravel is very little different from that of sand (see page 87), and what in general was said about the weight of the latter applies with equal force to gravel, since it is but sand on a little larger scale. Gravel is heavier, as a rule, than broken stone, since gravel is generally better graded, and hence more dense. A cubic foot of pit-gravel will weigh from 90 to 115 lbs., varying according to the degree of grading, the wetness and compactness, even as the sand.

Screened vs. Unscreened Gravel.—Naturally mixed bank sand and gravel are sometimes found in the right proportions for making concrete, requiring but little if any sand to perfect the blend. Great care should be exercised in using this class of material, owing to the likelihood of there being far too much sand for the gravel. An excess of sand is weakening to concrete. Frequent tests should be made to see that the proportions of the coarse and fine grains are correct, as the quantity of sand in different parts of the same gravel bank may vary greatly. In other words, care must be taken to see that the proportions are about right when using such ready mixed gravel.

While natural gravel is sometimes so uniformly mixed as to be suitable for use without screening, either with or without additional sand, it is generally far more satisfactory to screen the sand out of the gravel and prepare the materials in the usual way. The gravel should be screened to at least two sizes, separated by a ¼-inch screen, and remixed, in order that the proportions may be reasonably definite. Better proportions and more uniform results will be obtained by screening out the sand and small particles and remixing them in determined quantity with the gravel. This is especially important in the case of reinforced concrete work, as the run of the bank rarely contains sufficient coarse stone to make a dense concrete.

The increased value of the remixed aggregate over the natural material will generally more than justify the additional expense, as unscreened gravel requires a larger quantity of cement than graded gravel and sand to attain equal strength. Consequently the author is in favor of separating the gravel into as many parts as is consistent with economy for the work in hand. Even on small work he believes it preferable to screen out the sand and remix it in the proportions.

Gravel-Broken Stone Combination.—A mixture of gravel and broken stone may be used (see page 111). Gravel, when specified to be mixed with broken stone, should be mixed with the broken stone in the proportion not exceeding 50 per cent.

Washing Gravel.—Gravel frequently requires washing to remove the coating of clay or loam from the pebbles. The objection to the washing of sand does not apply with the same force to gravel, as the gravel is not required to contain the very fine particles that

should be a constituent of all good sand. Very often, however, the washing removes some of the sand, which needlessly increases the percentage of voids. The washing should be done in such a manner as to remove no sand, and as a rule only part of the clay. This precaution applies especially to unscreened gravel that requires washing.

Rejection of Gravel.—At any time, if the gravel delivered does not fully meet the requirements as stated above, it should be rejected.

Shale gravel should not be used.

No rotten stone whatever should be allowed.

Piles or heaps having any admixture of dirt or stone of a larger size than specified should be unconditionally rejected.

Do not accept slimy gravel, nor gravel containing many mud balls or a large percentage of gravel cemented with mud. That is to say, in using gravel, that containing mud or gravel cemented into lumps with mud should be rejected.

Unless first very carefully examined, both physically and chemically, the use of "chats" should not be permitted. (See page 86.)

DETERMINATIONS FOR GRAVEL

The usual determinations for gravel are: Size of pebbles, mineral composition of pebbles, cleanness and amount of voids. Any of the methods used in making determinations for sand (see page 93) can be used in making determinations for gravel. As a matter of fact, visual examination is usually all that is necessary for any of the determinations except for voids and for exact analysis of the various sizes of pebbles composing the gravel.

Sand.—The amount of sand in the gravel can be estimated by sifting samples of it.

Cleanness.—The presence of dirt in gravel may readily be determined by putting a handful of the gravel in a small strainer and turning clean water on it, catching the water in a glass dish. After a while the dirt will settle in the bottom of the dish. (See also page 95.)

Washed vs. Unwashed Gravel.—Before accepting gravel containing a large percentage of foreign matter tests should be made of that particular gravel, washed and unwashed.

Determination of Voids.—Before adopting a gravel for any important work the per cent of voids should be determined; and if the result is not entirely satisfactory the gravel should be separated into several sizes by screening, and the various sizes should be combined in different proportions to determine whether or not the per cent of voids can be reduced. An advantageous combination can sometimes be discovered by inspection, and may always be found by trial as mentioned on page 109.

Voids in gravel may be determined with fair accuracy by measuring the amount of water required to fill the voids in a given volume of gravel; owing to the larger particles the error due to entrapped air is smaller than with sand. However, for gravel containing much

fine material this method is not reliable on account of the difficulty of excluding all the air. (See page 99.)

Voids in gravel may be determined somewhat more accurately by weighing a known volume and calculating the volume of solid material by means of its specific gravity (see page 99). If there is much moisture present this must be first eliminated by drying, otherwise a considerable error will be introduced. If V=volume of gravel, W=weight of volume V, G=specific gravity of solid stone, and P= percentage of voids, then

$$P=1-W/V(G\times 62.5).$$

The specific gravity of gravel is practically constant and equal to 2.65, the same as for sand.

Care must be taken in filling the vessel with gravel so that the degree of compactness will be uniform. The voids should preferably be determined with the gravel simply shoveled into the receptacle or slightly compacted by dropping a short distance. Moderate ramming or shaking will readily reduce the volume 10 per cent, and heavy ramming as much as 15 per cent.

Volumetric Synthesis.—Having determined the particular gravel which is to be used on any piece of work, a simple and accurate way of determining the most advantageous combination of sizes of pebbles to produce a minimum per cent of voids is by successive trials. For this it is only necessary to have good scales and a strong and rigid cylinder, say, a piece of 10- or 12-inch vitrified pipe capped at one end, or a strong wooden box, preferably metal-lined. Carefully fill the pipe or box with the coarsest gravel to a depth of a foot or more, tamping the material slightly as it is being put in, and note the height to which the pipe is filled. A line may be made around the pipe on the inside to indicate the depth of the stone. Weigh the pipe or box before filling and after being filled, thus checking weight of pebbles alone. Next take a new portion of the coarse material and add, say, one-tenth of its weight of the next finer material, and repeat the above trial with this mixture. If the amount of this mixture compacted into the pipe or box weighs more than that of the corresponding coarse material, then this mixture is the better for making concrete. On the other hand, if the weight of this mixture is less, then this mixture is not as good for concrete as the corresponding coarse material. The most advantageous combination of sizes to produce a minimum per cent of voids will be found by successive trials, and this will result in the most economical combination.

PREPARATION OF GRAVEL

Gravel is prepared for use by (1) Screening, (2) Washing, if necessary, and (3) Heating, if necessary, for winter work. The preparation of gravel is practically the same as that required for sand, excepting of course as to the size of the screens. For methods of screening and washing gravel, see pages 102 and 103, and for methods of heating gravel, see Art. 33, page 356.

Art. 10.—Broken Stone for Concrete

The term *broken stone* ordinarily signifies the product of a stone crusher or the result of hand-breaking by hammering large blocks of stone; but the term may also include gravel (see Art. 9).

Classification of Broken Stone.—Rocks which are commonly used for concrete are commercially classified as (1) traps, (2) granites, (3) limestones, (4) conglomerates, and (5) sandstones.

Trap rocks include dark green to black, heavy, close-grained, tough rocks of igneous origin, thus covering a variety of rock whose mineralogical names are diabase, gabbro, norite, etc.

Granites include not only true granite, but also the lighter-colored, less dense rock, such as gneiss, mica schist, syenite, etc.

Conglomerate, often called pudding stone, is essentially a very coarse-grained sandstone.

Rocks of a volcanic nature may be divided into the following classes: Basalts, traps, dense lavas, pumice, etc.

Choice or Selection of Broken Stone.—The purpose for which the concrete is intended must always influence the selection of the stone. That is to say, the care required in the selection of a proper quality of broken stone will depend upon the required strength of the concrete. For very strong concrete, a hard stone without any surface scale is necessary; a rich mortar will not be able to make up a deficiency in the strength of the stone. For a medium concrete a very hard rock need not be insisted upon, but rather one which presents a good surface to which mortar may adhere is the principal requirement. In other words, if a low strength is sufficient, and consequently a poor mortar is to be used, but little will be gained by having a very strong rock from which to obtain broken stone. In such cases, limestone will probably answer.

The best material for broken stone is a rather hard and tough rock, which breaks into angular fragments with rather rough surfaces. Almost any moderately hard rock, provided it is not subject to decay, is suitable for use in concrete.

The kinds of stone generally used are trap, limestone, and sandstone. Broken trap rock is the best aggregate for concrete work, as it is harder and stronger than the others and is a better fire resistant. The next in value is broken granite. Marble, limestone, and slag make good aggregates, in the order named, there being objections to marble and limestone where concrete is used as a fireproofing. The harder and denser sandstones make good broken stone for concrete; while the looser-textured sandstones, shales, and slates are poor for this purpose, although occasionally they are used.

As already stated, trap rock makes the best, hardest, and most durable broken stone for concrete work. This rock breaks into sharp, angular pieces, is fine grained, and is of free fracture, without laminated, or scaling surfaces. Owing to the texture of the stone, the cement adheres strongly to it. Crushed trap is an exceedingly hard, clean, flint-like stone, which bonds well and furnishes a concrete

of great strength; it also withstands heat better than most stone. It is especially good for reinforced concrete construction in that it possesses great crushing strength and considerable transverse resistance, and tends to increase the strength of the concrete shear. All things considered, trap rock makes the best aggregate. It is unfortunate, however, that trap rock cannot be used in all parts of the country since it is not obtainable unless shipped in.

Crushed granite is also very good, unless the fragments are bruised in the crushing. Not only true granite, but also mica schists, syenite, diorite, gneiss, etc., which are frequently called granites, are just as good for concrete work, and are usually less expensive.

Limestone is suitable for some kinds of concrete work; but its strength is not so great as that of granite or trap rock. Next to trap, however, the hard, tough, crystalline limestones make perhaps the best all-around concrete aggregate, being by far the most used. Some limestones seem to be particularly adapted to concrete making, as the cement adheres to the surface so firmly. In fact, cement adheres to limestone better than to other rocks. Hard limestone is good and durable, except as to its ability to withstand fire. It will calcine or turn to lime when subjected to great heat, and is, therefore, objectionable for building construction.

Frequently conglomerate (often called pudding stones or boulders) in broken form is used as an aggregate for concrete. This is a very coarse-grained sandstone and is not so good as trap rock or gravel, but it produces concrete suitable for most purposes. Owing to the irregular shape and surfaces of such stones, their particles do not lie so close together as do those of trap rock. Such stones are liable to be of a coarse, granular, quartz-like nature, in which the cohesion is small, so that the keying or adhesion between the cement and the aggregates is not so good as in trap rock.

Sandstones are sometimes said to be better than limestones, but this will depend on their relative hardness and structure, and the use to which the concrete is to be put; no general rule will apply, as the value of sandstone for concrete is very variable according to its texture. Some grades are very compact, hard and tough, and make good concrete; other grades are friable. While some sandstones are used with excellent results, as a rule they are not considered strong enough on account of lack of hardness and their liability to crumble, and from the fact that their surfaces are likely to be unstable.

The poorest aggregates are slate and shale, which are of a laminated structure and break in such shapes that they will not pack closely. Their crushing and shearing strength is low. (See page 125.)

Broken Stone-Gravel Combination.—A mixture of broken stone and gravel gives good results. The gravel assists the compacting of the mass, and the fragments of broken stone furnish a good bond. A mixture of this kind also leaves but a small percentage of voids in the mass, and this decreases the amount of mortar required. (See also page 107.

GENERAL REQUIREMENTS

Many of the points mentioned concerning the selection of a good sand are also applicable to broken stone (see Art. 8).

Quality of Broken Stone.—Broken stone used in concrete work should possess three qualities: (1) It should be hard and strong, so as to resist crushing and shearing or transverse stresses; (2) it should have surface texture that will permit the cement mortar to adhere to its surface; and (3) where the concrete is to be used for building construction, such as in reinforced work, and for fireproofing, it should possess refractory, or fire-resisting, qualities.

Broken stone should be hard and durable. Concrete cannot be strong if made of weak stone. In general, the harder the stone the stronger will be the concrete under compression. Any stone is suitable for concrete which is durable and has sufficient strength so that the strength of the concrete will not be limited by the strength of the stone. Beyond this minimum, great strength is of little advantage. Aggregates containing soft, flat or elongated particles, should be excluded from important structures.

Good rock will generally show its quality in the manner of breaking; for instance, if it breaks in such a way as to allow the smallest spaces or interstices between the particles, it will make the strongest concrete for construction purposes, because the voids can be most economically filled with mortar. That is to say, if the rock breaks up on crushing or pounding into "bastards," or irregular, chunky particles, with no apparent planes of cleavage, having what is known in geology as a "conchoidal fracture," it is satisfactory. In other words, stone should be broken in cubical forms with angular fracture. On the other hand, if the rock breaks up into more or less regular pieces, flat and slaty-like, it is, as a rule, unsuitable, since such material is more likely to be soft and brittle, and the pieces are at any rate unsuited by their shape to incorporate well in concrete; that is, such stones are liable to break under pressure or while being rammed into place, and thus leave two uncemented surfaces. Besides, it is almost impossible to ram or tamp such stone into as dense and compact a mass as that in cubical fracture.

For all classes of concrete, a stone which breaks in approximately cubical pieces rather than in long, thin, splintery fragments should be preferred. The harder and tougher the quality of the rock, the less danger of its splitting into laminated or flaky shapes.

When old masonry is torn down, the stones are sometimes crushed for use in concrete, but such stones, having particles of mortar adhering to the surfaces, will not be of first quality for the purpose; their cheapness, however, will frequently outweigh such objections.

Volcanic Rocks.—All rock of volcanic origin for use as a concrete aggregate should be entirely free from decomposed parts and should show no signs of expansion, disintegration, or dissolution after having been immersed in water for 72 hours. Volcanic rocks should be dense, thoroughly vitrified, not scoriaceous, show a clean fracture when broken, be homogeneous and free from marked cellular structure.

Granite.—In some localities, it is the practice to break granite spalls so as to form the aggregate for concrete construction. Such granite should be fine and uniform in grain and color, and perfectly sound. It should be free from sap, seams, dries, cracks, large crystals of feldspar, dirt, argillaceous or organic materials, decomposed particles, and defects of any kind calculated to impair its strength, durability or appearance. Granite has the disadvantage of spalling too readily under the effect of fire, being otherwise satisfactory. It should not be used if trap or hard limestone is available.

Limestone.—All limestone for use as a concrete aggregate should be dense, uniform, and homogeneous in structure and composition. It should have small even grains and crystalline texture. Fractures should be clean and free from large flaws, or defects of any kind calculated to impair its strength or durability. Limestone is frequently prohibited on the ground of its lack of durability—not being a good resistant of either fire or acid-fumes. In fact, the building departments of many of the large cities will not permit the use of limestone for reinforced concrete construction.

Sandstone.—Sandstone should be in quality and freedom from defects fully equal to the limestone specified above. Many sandstones are of deficient strength, and should be used only after determination of their strength. Soft or shaly sandstone should not be used. The great objection to sandstones is their lack of toughness and their porosity; they are usually weak, and, unless thoroughly soaked before mixing, will give trouble by absorbing excessive amounts of water, thus preventing plasticity and a thorough mixture.

Shape of Broken Stone.—Broken stone should be nearly cubical in in form, as thin, flat particles will not pack well. The shape of the fragments has an important effect on the proportion of voids in the mass. (See page 71.)

Size of Broken Stone.—In measuring broken stone, the size of the stone is determined by the size of the ring through which it will pass. The size to which an aggregate should be reduced by crushing depends upon the class of structure in which the stone is to be used. The stone should be broken small enough to be conveniently handled and easily incorporated with the mortar; but, other things being the same, the larger the stone, the stronger and the denser the concrete. Therefore, the largest stone should be used that is consistent with proper placing, taking into account the dimensions of the form, and the size and disposition of the reinforcing bars or wire fabric. In using a large stone, care must be taken to prevent it from separating from the concrete, and to prevent it from moving the reinforcement out of place (see page 71). The aggregate for small work should have small sizes of stone.

Stone for reinforced concrete varies from ½ inch to 1½ inches, that passing a ¾-inch ring or mesh being most common. In reinforced concrete beams and columns the maximum size of stones should generally be ¾ inch to 1 inch. The reason that the stones should be small is so that they will pack around the reinforcement and not leave voids. In arches a good size, if no small meshes are employed

in the reinforcement, is 2 inches to $2\frac{1}{2}$ inches. For plain concrete the stone is usually broken to pass any way through a 2- or $2\frac{1}{2}$-inch ring. For large masses of concrete, $2\frac{1}{2}$-inch stone is usually considered the maximum size, but for 12-inch walls and the usual class of concrete construction, $\frac{3}{4}$-inch will be found sufficiently large.

Grading Broken Stone.—The stone should be uniform, that is, there should not be just a few of the largest size of stones, or an excess of the same; also there should not be an excess of very small particles. In other words, the broken stone should consist of particles of variable size from those of the size of the largest sand to the largest stones, so that the small pieces may fill the voids of the large ones. The finer the stone the greater the surface to be coated, and consequently the greater the amount of cement required. A graduated mixture of the different sizes of stone produces a denser, stronger, and more economical concrete than stone of a uniform size.

Unloading of the stone is apt to separate the large stones from the small ones. The whole pile, as well as different deliveries, should be well mixed, so that different batches of concrete will be as near alike as possible.

Cleanness of Broken Stone.—Broken stone should be clean and free from dust, dirt and other foreign matter, such as vegetable mold, scale, or loam, which clinging to the surface will reduce the strength of the concrete. Disintegrated stone or broken stone containing mica should be rejected. There should not be over 1 per cent of rotten stone. Dumping stone in dirty places may result in a large quantity of dirt getting into a batch of concrete.

Run of the Crusher.—The latest practice in making concrete is to use stone as it comes from the crusher, without screening it. While such stone, termed run of the crusher, contains broken stone of a size specified, it also has smaller particles of stone and such stone dust as is carried along with the broken stone from the crusher. Its use reduces the proportion of sand required, but the amount of this reduction should be determined by analysis. In other words, when the run of the crusher is used, the proportion of the cement and sand must be changed, because the stone dust takes the place of sand; and if mixed with the broken stone, using the same proportion as was specified for clean broken stone, a much poorer concrete will result, a fact which should always be borne in mind. The author has seen crusher-run used as if it were screened stone and the stated proportion of sand added religiously, with the result that the mixture was exceedingly "mushy" and afterwards, in spots, crumbly.

In using run-of-crusher material, study crusher conditions so as to obtain a reasonably uniform product. Since the proportion of large and small particles in the run of the crusher depends considerably upon the character of the stone which is being broken up, and perhaps to some extent on the crusher itself, these proportions should invariably be tested at frequent intervals during the progress of the work, and the amount of sand to be added to make a good concrete should be determined by trial tests (see page 145), so that the resulting percentage of voids shall be as small as it is practicable to make it.

When it is specified that run-of-the-crusher stone is to be used, it should not be taken to mean that long, thin, flat pieces of stone may be used; they are an element of weakness and should be excluded. Crusher-run, sometimes to the quarryman, means everything in his quarry that can be got on a shovel. This means additional worry for the inspector. In using crusher run the very finest dust should be washed or screened out, as it tends to coat the large pieces and prevent the cement from adhering to them. If the rock dust is not uniformly distributed it may be best to screen it out and use it as sand. Of course if this dust is rotten stone ground up, it must be screened out or otherwise removed.

Screened vs. Unscreened Broken Stone.—It is frequently required that the broken stone shall be freed from all fine material, resulting from the crushing of the stone, before the mortar is added to form concrete. The wisdom of this requirement is not always clear and depends upon the kind of stone; unless, as described later, it is intended to mix definite proportions of several sizes of carefully screened broken stone. Quarry tailings, etc., in crushed stone are not a positive detriment, as is sometimes supposed. Some forms of crusher dust or screenings give, if not too fine, excellent results in mortar; this is especially true of limestone screenings. It is invariably found that unscreened stone or the run of the crusher has a far less per cent of voids than screened stone, thus giving greater density and consequently greater strength; effecting also a saving in cement, and, if limy, acting as binder besides.

The objection to a large percentage of stone dust is that, as a rule, rock which, when crushed, gives a large percentage of dust generally contains considerable rotten rock, which is ground to dust in its passage through the crusher. Again, if a stone is covered with a layer of moistened, floury dust, it cannot be so readily brought in direct contact with the mortar, and if the mortar does not reach the stone it is made less rich by the dust, which acts as so much fine sand.

Unless care is exercised, the true run of the crusher will not be obtained, for, if the crushed stone is poured into a heap, a separation of the different sizes is sure to occur, in a greater or a less degree. That is to say, there is apt to be a separation of the coarse particles from the fine as they roll down the pile so that less homogeneous proportions can be attained. In other words, the fine material collects in certain parts of the bin or pile, making the proportion irregular, so that one batch of concrete may have a rich mortar with a comparatively large amount of stone, while another may have a poor mortar with but little stone. To prevent this, the crushed stone should fall directly into the gauge-box from the crusher.

Even when the true run of the crusher is obtained, it is evident that the product may not be uniform, as slight variations in the hardness or texture of the stone may produce great variations in the size of the crushed material, the percentage of fine particles, etc.

Owing to the unavoidable tendency of grades to separate in the several handlings intervening between crushing and using, the fine material is more than likely to be bunched, and for this reason it will

generally be necessary to screen out the rock dust or fine stuff. If, therefore, all of that portion of the broken stone finer than, say, one-eighth of an inch, be screened out and used as so much sand in making the mortar, the resulting concrete will be better and more nearly uniform in quality. In other words, a more accurate method of using crusher-run is to screen out the fine material and then mix in the required proportions, using the fine particles to replace sand in the mortar.

Specific Gravity of Stone.—The specific gravity of hard stone suitable for concrete varies generally within narrow limits, and can often be used to advantage in calculating weight and proportions of voids. Specific gravity of various rocks is about as follows:

Trap	2.8 to 3.0
Granite	2.6 to 2.8
Limestone	2.6 to 2.7
Conglomerate	2.5 to 2.8
Sandstone	2.3 to 2.6

Weight of Broken Stone.—The weight of crushed or broken stone varies with the amount of compacting it has received, whether by being dropped into the bin or car, or by being shaken during transportation. It will also vary with the relative size and grading, the less the number of gradings and the smaller the individual pieces the lighter the weight per cubic foot. A lot of broken stone, mostly one size, will average from 75 to 90 lbs. per cu. ft., depending on the quality of the rock, trap being heavier than most other stone; whereas, if well graded, the weight may exceed 100 to 120 lbs. The amount of broken limestone per cu. ft. is about 85 to 95 lbs., or about 2,300 to 2,600 lbs. per cu. yd. A cu. yd. of crushed stone of 2.7 specific gravity and 45 per cent voids will weigh almost exactly 2,500 lbs., a value frequently assumed.

Voids in Broken Stone.—The percentage of voids in broken stone varies with the uniformity of the stone, its shape and degree of compactness. It also varies with the nature of the stone; whether it is broken by hand or by crusher; with the kind of crusher used, and upon whether it is screened or crusher-run product. Voids in broken stone will range from 30 to 55 per cent, seldom exceeding 52 per cent, however, even when the fragments are of uniform size and the stone is shoveled loose into the measuring box. Voids in loose broken stone, crusher-run, with the fine material screened out, will generally range from 43 to 48 per cent. Heavy ramming will reduce the voids in loose stone about 15 per cent. If well shaken or rammed, as in the placing of concrete, the volume can readily be reduced 10 per cent. The voids in broken stone usually run from 40 to 50 per cent of the volume.

Caring for Broken Stone upon the Works.—Where a crusher is used on the works, the different grades of screened broken stone should be deposited in bins or piles properly labeled, so that there can be no mistake made by the man in charge of the mixer or the dif-

ferent gangs of men when there comes a call for a change of size of broken stone in the concrete mixture.

If, on the other hand, the broken stone is received on the works by the carload, it should be seen to that each carload is labeled as to its grade, and that it is unloaded into its proper bin or pile. As a safeguard where the broken stone is received by the carload, and not inspected as to its grade, and especially when coming from an unreliable yard, it is well to run the stone through screens so arranged and spouted beneath that the different grades reach their proper piles.

Too much stress cannot be placed upon the importance of classifying the different grades or sizes of broken stone, and keeping each within its sphere for its proper installation in the structure. For each grade of broken stone there is a definite amount of sand and a fixed proportion of cement within limits required to make a homogeneous concrete; and without this homogeneity of mass, a weakness in the work results, just as would be the case if poor cement were allowed to enter or left out entirely. As there is a safeguard against this latter, so there is against allowing the different grades of broken stone to be interchanged, and this is care on the part of the inspector.

To be more explicit in regard to the consequences which are bound to exist without proper care, let us suppose, for instance, that the mixture which is being run through the mixer is for beams or floors in a reinforced concrete building, and the measuring devices are set for the proper amount of sand and cement for a $3/4$—$1/4$ gauge stone. Through carelessness, let us suppose that the mixer hopper has been charged with a few buckets of a $2\frac{1}{2}$—1 gauge stone along with the $3/4$—$1/4$ gauge. When this enters the measuring hopper there is neither time nor ready means of changing the sand and cement to agree, provided the tender knew enough. Consequently, the larger stone goes through with the proportions of sand and cement for the smaller stone,—in other words, with voids unfilled, and the concrete far from being homogeneous. But the trouble does not end here, for it is impossible to work the large size stone into a small beam, or around the steel reinforcement without allowing voids to form, and again homegeneity is sacrificed. Thus a slip in one respect has weakened the structure.

Platforms should invariably be provided upon which the broken stone may be placed when brought upon the line of the work, and any not so placed should be rejected by the inspector. (See Art. 7, page 73.

Rejection of Broken Stone.—At any time the broken stone delivered does not fully meet the requirements as stated above, it should be rejected.

The quarries selling broken stone sometimes attempt to dispose of broken stone mixed with quarry refuse, stone dust, etc., and each carload or wagon load should be carefully inspected, and rejected if the material is not as perfectly satisfactory as will give first-class results when mixed in concrete. Do not accept stone with a large percentage of tailings, nor stone with more than 15 per cent of stone

dust. Too much fine stone in the aggregate is detrimental to the strength of the concrete.

Do not accept stone with more than 1 per cent of weathered rock. No soapstone or rotten stone whatever should be allowed. Decomposed stone should be rejected.

Soft white limestone should be excluded. For fireproof construction some of the limestones and rocks containing feldspar should be avoided. When considerable fire-resistance is essential, i. e., reinforced concrete buildings, limestone and like materials liable to disintegrate or become calcined under the action of fire should not be used.

Slaty or shaly rocks are not good material for concrete aggregate and should never be so employed.

Unless first very carefully examined, both physically and chemically, the use of "chats" should not be permitted. (See page 86.)

Piles or heaps of broken stone having admixture of dirt or stone of a larger size than specified should be unconditionally rejected.

Do not accept stone a noticeable percentage of which goes to pieces under the rammer. The stones should not have incipient cracks, so that they will crush under the rammer. Stone which yields a great deal of fine material in crushing should be avoided, as such stone is not strong.

Any stone which shows a tendency to break into flat, thin pieces should also be rejected. Soft, flat or elongated particles do not make a satisfactory material for coarse aggregate. Stone which breaks more easily in some directions than others, or exhibits cleavage, is hard to tamp compactly. Mica schist is of this class, and should be avoided for reinforced concrete, though it may be allowed for massive construction.

Occasionally broken stone comes from a formation that is rather brittle and the crusher causes small cracks that extend throughout the stone and are apt to be a source of weakness. Such stone should be rejected.

DETERMINATIONS FOR BROKEN STONE

The usual determinations for broken stone are: Shape of particles, size of particles, mineral composition of particles, cleanness and amount of voids. Any of the methods used in making determinations for sand (see page 93) can be used in making determinations for broken stone. As a matter of fact, visual examination is usually all that is necessary for any of the determinations except for voids and for exact analysis of the various sizes of particles composing the broken stone. Tests, however, should be made for crushing resistance and also for fire resistance when used in building construction.

Toughness.—Tap vigorously with a light carpenter's hammer four or five times in quick succession. Stone should begin to crush under this impact before it spalls, splits or otherwise fractures. Marked fragility should cause rejection. See that stone particles are all cleanly broken and have no incipient fractures.

Some stones, more particularly of a shaly nature, are so tender

that they may be broken between the fingers; such, evidently, are not suitable material.

Cleanness.—The presence of dirt in broken stone may readily be determined by putting a handful of the broken stone in a small strainer and turning clean water on it, catching the water in a glass dish. After a while the dirt will settle in the bottom of the dish. (See also page 95.)

Crushing Resistance.—The suitability of any particular stone for making concrete may be tested by using it in making a cube of concrete and crushing it at any age desired; if the fragments of the stone pull out of the mortar, the adhesion of the cement limits the strength of the concrete, but if the fragments of stone are broken across, then the strength of the concrete is limited by the shearing strength of the stone.

Fire Resistance.—Place an average sample of the broken stone on an ordinary shovel or in a pan and hold over a hot fire until the broken stone heats a dull red. The stone should then be suddenly chilled with cold water. It should stand both heating and chilling without softening, spalling or checking. This test is an important one, as many hard stones, especially the lime rocks and granite, will crumble rapidly under a small amount of heat.

Acid Resistance.—A sample of broken stone should be treated with strong or concentrated muriatic acid, which may be applied by pouring on the acid or by immersing the broken stone itself in a vessel of the acid. A glass dish should preferably be used for this purpose. Unfitness of the stone will be indicated by a violent effervescence, accompanied by rapid crumbling. Hard limestones and dolomites (magnesium limestones) are attacked by acid, but less vigorously than soft limestones and marbles (a type of metamorphic limestone). This distinction will establish a convenient basis for a choice between two or more kinds of limestone proposed for use.

Determination of Voids.—The per cent of voids in a mass of broken stone may be determined by either of the two methods employed in finding the voids in sand. (See pages 98 and 99.)

Voids in broken stone may be determined with fair accuracy by measuring the amount of water required to fill the voids in a given volume of broken stone. The method by pouring water into the mass is reasonably accurate for stone having but little fine material in it; but for ordinary crusher-run broken stone, the material should be dropped into the water and not the water poured into the stone, so that the formation of air bubbles will be decreased. The percentage of error, however, due to such cause, is far less than it is in a similar test of sand, and the error for ordinary work is too small to have any practical effect on the result. If the stone is porous, it is best to wet it, so as to determine the voids between the fragments; for the water absorbed by the material should not be included in the voids, since porous stone is usually dampened when mixed in concrete. In wetting the broken stone before determining the voids, no loose water should remain in the pile. The voids may be determined for the stone loose or compacted.

Voids in broken stone may be determined somewhat more accurately by weighing a known volume and calculating the volume of solid material by means of its specific gravity. (See page 116.) If V=volume of broken stone, W=weight of volume V, G=specific gravity of solid stone, and P=percentage of voids, then

$$P=1-W/V\,(G\times 62.5).$$

Care must be taken in filling the vessel with broken stone, so that the degree of compactness will be uniform. The voids should preferably be determined with the broken stone simply shoveled into the receptacle or slightly compacted by dropping a short distance.

Volumetric Synthesis.—Having determined the particular broken stone which is to be used on any piece of work, a simple and accurate way of determining the most advantageous combination of sizes of particles to produce a minimum per cent of voids is by successive trials, as described on page 109, for gravel.

PREPARATION OF BROKEN STONE

Broken stone may be produced by breaking quarry stone in a stone-crusher, and separating it from the dust and large fragments, by passing it through an inclined cylindrical revolving screen. When but a small quantity of concrete is to be made, and broken stone cannot be purchased in the vicinity, the stone for concrete may be broken by hand, but this is an extremely tedious process, and should be avoided whenever possible. The aggregate after preparation should be free from all dirt, decomposed rock, argillaceous and organic material.

Screening.—Crushed stone may require removal of the dust. If there is much dust present it may be removed by means of a small mesh screen.

Washing.—Another way to remove the dust is to wash the crushed stone in a barrel having a wire-sieve bottom; the water running through the stone will carry with it all the dust. (See page 103.)

Stone Crushers.—Stone crushers are of two general types, the jaw crusher and the gyratory crusher. The former is better adapted to small or portable plants, while the latter is generally used in large stationary plants.

The jaw-breaker crusher consists of two jaws, one fixed and the other hinged at the top, the lower end being moved backward and forward through a very small arc by means of a toggle joint or other mechanism. The motion is imparted by the eccentric shaft, which, in revolving, raises and lowers the "pitman," whose lower end is connected by toggles with the lower end of the movable jaw. The distance between the jaws at the bottom regulates the size of the stone passing through them—that is, the size of the largest fragments or particles, and this distance may be adjusted at will by using longer or shorter toggles. The size of a jaw crusher is designated by the opening into which the stone is introduced. A convenient size of jaw crusher for a semi-portable plant is about 10x16 in. This will crush

from 50 to 100 cu. yds. per day, depending upon the texture of the stone and the sizes of the largest particles desired.

The gyratory crusher consists essentially of a corrugated cone of chilled iron, called the breaking head, within an inverted conical chamber or shell, which is lined with chilled iron pieces. The vertical shaft bearing the breaking head is pivoted at the upper end, while the lower end travels in a small circle; the gyratory motion of the head being produced by an eccentric keyed to the lower end of the cone shaft, so that it approaches successively each element of the shell. In other words, as the shaft revolves the cone is given a sort of a rocking or eccentric motion which continually directs it toward, and then away from, different portions of the shell. The size of the broken stone can be regulated by raising or lowering the breaking head or the cone on the shaft. The size of the crusher is determined by the width of the opening between the top of the cone and the shell, and the circumference. A No. 4 gyratory crusher with openings 8x27 inches is usually recommended for a concrete plant producing about 200 cubic yards per day.

Stone crushers are made of various sizes having capacities up to one hundred and ten tons per hour. The capacity of any crusher varies with many conditions. The kind of stone and the sizes of the largest particles affect the capacity of a crusher. The efficiency of a crusher is higher on a short time test than on a long time test, and while a crusher may be used up to its rated capacity for an hour or for a day, the average efficiency for a month will be found much less than catalogue figures, usually about 55 per cent of the rated capacity, because they are based on maximum capacity with continuous feeding, while in practice there are likely to be unavoidable delays.

Crusher Screens.—Crushing plants are usually provided with revolving screens, made in sections from 3 to 5 ft. long, and of a diameter of 2 to 4 ft., into which the broken stone is delivered from the crusher; perforations in these screens allowing the stone to fall into bins placed beneath, the holes being such as to separate the material into the sizes desired. For concrete, unless two or more sizes of stone are mixed, only two sizes of mesh are required, the maximum size and a ¼-inch screen to remove the dust.

Crusher Plants.—If the reader is interested in the arrangement of crusher plants, he can obtain a description of many plants, successful and economical in operation, from almost any of the standard books now published on the subject of Concrete or Reinforced Concrete, and in the volumes of *Engineering and Contracting, Engineering News* and *Engineering Record.*

The following general principles may be laid down:

When large amounts of concrete are required, and the stone is to be crushed on the work, the arrangement of the crusher plant should receive careful study to facilitate the handling of the rock to and from the crusher. The broken stone should be discharged from the crusher into bins, from which the wheelbarrows, carts or cars may be filled by gravity, or from which the broken stone may be led directly to the mixer through a chute or other form of conveyor.

Art. 11.—Cinders, Slag and Miscellaneous Materials for Concrete

Concrete is veritably a huge mixing pot, in which the odds and ends of otherwise waste material and refuse, so long as it is hard and tough, may be indiscriminately intermingled and by the magic of cement converted into a smooth, dense, hard and durable stone of any form and dimensions whatsoever. Thus, brick-bats, broken glass, broken stone (see Art. 10), burnt clay, cinders, coke-breeze, coral, crockery, flints, gravel (see Art. 9), oyster shells, pan-breeze, pumice, sea shells, shale, slack-coal, slag, slate, and what not—much of which is otherwise only worthless débris—may be utilized on occasion as filler for concrete, and so made to render efficient service.

CINDERS

Cinders are lighter, more porous, and more friable than broken stone or gravel; but cinders are valuable as an aggregate for concrete where lightness is more important than strength, as in the successive floors of tall buildings, in concrete for fireproofing purposes and for very low stresses. Being porous and light in weight, cinders are not as strong as broken stone or gravel, and must not be used where strength is required, nor should cinder concrete (see Art. 31) be subjected to load before one month old. Cinders offer many advantages as an aggregate for concrete, but must be used cautiously as they often contain dangerous impurities and particles of unburned coal. In any structure where the strength of the concrete is a matter of importance, cinders should not be used without a thorough inspection. See Art. 37, page 375, for uses of cinder concrete.

Quality of Cinders.—Cinders should be composed of hard, clean, vitreous clinker, free from ashes, sulphides and unburned coal. One great objection to cinders is the great difficulty of getting a good quality. If hard coal, steam-furnace cinders, thoroughly burned out, were always obtainable it would be a different matter, but most of the stuff offered as cinders is little better than coal-ash, and usually full of unignited particles. Cinders should be of good, clean, crushed, vitrified clinkers, as the ordinary cinders are not fit for fireproof work. Those from anthracite coal are usually the best owing to being harder, generally more dense and less liable to contain injurious amounts of sulphur.

Cinders for use in concrete should not contain many, if any, fine ashes, since they present too much surface to be covered by the cement. As generally furnished, cinders are composed largely of ashes and are very unsuitable for concrete. Cinders made by power plants, sometimes called steam-furnace or steam cinders, are much better suited for concrete than ashes from household furnaces, because the fires in the former are hotter and fuse most of the ashes into cinders or clinkers, leaving little fine material. In other words, good boiler furnace cinders from power plants make the best cinder concrete. Steam-furnace cinders that have been drenched with water as soon as drawn from the furnace, generally called black cinders, are better

than those that have been allowed to burn in the pile, since they contain fewer fine ashes. Cinders for reinforced concrete should not contain more than 5 per cent of ash, and it is preferable to keep the percentage down for any other concrete. Wood ashes should never be used, as they contain a great deal of fine material, and also since a considerable part of them is soluble.

One possible objection to the use of cinders lies in the fact that they frequently contain sulphur and other chemicals which may produce corrosion of the steel reinforcement. In fact, cinders usually contain much sulphur. Steel reinforcement laid in cinders, if moisture be present, will rapidly corrode, on account of the formation of sulphuric acid, due to oxidation of the sulphur and addition of water. Iron or steel pipe laid in a cinder fill should be surrounded by concrete or at least by clay.

Cinders for fireproofing work should be chosen carefully, as the presence of unburned coal will render such concrete the least fireproof, whereas it is supposed to be the most fireproof. In other words, the particles of unburned coal soon burn out in event of fire, leaving the concrete correspondingly pitted. Cinders for fireproofing should not contain more than 5 per cent of unconsumed coal, and for other purposes not more than 15 per cent.

Screening Cinders.—For good cinder concrete, it is often necessary to screen out the ashes and refuse and often to crush the coarse particles or large clinkers. When screening cinders which are to be used as an aggregate for fireproof concrete, all the large clinkers should be crushed to the desired size and used, as this is the material most desired. A cinder aggregate should really contain very little cinder, but should be nearly all clinkers which will pass through a 1-inch mesh sieve, and if very dirty they should in addition be passed over a $3/8$-inch mesh sieve. Usually a better mixture can be obtained by screening the fine stuff from the cinders and then mixing in a large proportion of sand, than by using unscreened material, although, if the fine stuff is uniformly distributed through the mass, it may be used without screening, and a less proportion of sand used. However, comparative tests should be made to determine whether or not the cinders should be screened.

Washing Cinders.—Cinders for concrete should be clean. It is sometimes necessary to wash them. (See page 103.)

Apparatus for Crushing Clinkers.—The large clinkers in cinders can be broken as described below, or when a large amount of clinkers are to be crushed a small rock crusher or a set of rolls will be more economical.

A slat platform can be constructed by bolting together flat bars of iron, about 1″x2″, separating the bars about 1 inch with spreaders. A curb or box rim is then put around this slat platform, and the platform set upon a couple of trestles about 2 ft. from the ground. The coarse particles or large clinkers are thrown in, crushed with a large flat hammer, or a flat iron concrete rammer. (See page 301.) As the clinkers are crushed to 1 inch or less they fall through the slats to the ground.

CRUSHED SLAG

Blast furnace slag, a by-product of the iron industry, is much used in some localities for concrete, and gives good results. In fact, good, clean, blast furnace slag makes a concrete that is not greatly inferior in strength to one in which broken stone or gravel is used. As some of the surfaces of slag are vitrified, or glazed, the adhesion of the concrete is not so strong as when broken stone is used, so that the concrete loses in tensile and shearing strengths. Crushed furnace slag is often used as an aggregate for fireproofing, making a hard, strong, fireproof concrete of 5 to 15 lbs. lighter weight per cu. ft. than broken stone or gravel. In fact, slag concrete is strictly fireproof. Furnace slag is not available in every locality, but is much used in some localities where a supply is convenient, and a good quality of broken stone or gravel not so convenient.

Quality of Slag.—Only the best quality of hot pot slag, free from dust and foreign matter, should be used. Some slags contain chemicals which are injurious to steel. Slag for concrete work should be nearly free from sulphur or other injurious agents and must be hard and not spongy. It should not be honey-combed.

Ordinary broken slag does not seem to be a desirable aggregate on account of its unstable chemical composition. Certain kinds of slag contain very injurious chemicals, such as sulphate of lime, etc. This is especially true of fresh slag, which usually carries a considerable percentage of sulphurous matter in the anhydrous condition (lacking water), and this content, when brought in contact with water or moisture, forms sulphuric acid, which in turn reacts upon the cement, decomposing it and liberating the obnoxious gas, hydrogen sulphide (recognizable by the familiar odor of bad eggs). While the sulphur affects the cement only to a limited extent, it is inclined to cause the iron or steel embedded in it to corrode, unless such material is thoroughly covered with the cement. Great care must therefore be taken if slag must be used to see that the sulphurous content is not excessive.

Seasoning may dissolve out the undesirable chemical compounds in the slag. When slag is to be used as an aggregate it should be allowed at least six months for aeration to get rid of some of the sulphur, which would otherwise disintegrate the concrete. In other words, a slag some months old is preferable, as aeration has had opportunity to remove the sulphur. Failures have occurred from using slag not sufficiently aerated, as otherwise it is a satisfactory aggregate. When molten slag is run into water, it is granulated, and much of the objectionable sulphur is washed out.

Proportions.—Slag makes good concrete if used with the proper proportion of mortar; for instance, 1:2:3 or 1:2:4. Owing to its porous nature, slag takes about 30 per cent more cement and mortar than either sand or stone. Slags from different furnaces vary widely and this point should be carefully investigated in determining on proportions.

Porosity of Slag.—Slag is objectionable chiefly on account of its porosity, requiring an excess of cement, as mentioned above, and a

very wet mixture. The slag is very dry and absorbs water in large quantities; the stock pile should, therefore, be kept soaking wet at all times. Otherwise the concrete may not set up well.

Reinforced Concrete.—If slag material is used for reinforced concrete, the reinforcement must be surrounded with fine, rich material (mortar).

Testing Slags.—All slags should be investigated by a good testing laboratory before being used. Chemical analysis should invariably be insisted upon before using an unknown slag. Judging a slag from the analysis of a small sample is not safe, because its composition varies with changes in the operation of the furnace or in the nature of the materials being smelted.

MISCELLANEOUS MATERIALS

Shale.—As a rule, a shaly rock, which is usually found in stratum formation, does not make a good aggregate for concrete work. Certain kinds of shale have great toughness when in the natural deposit, but fall to a powder or split into particles when exposed to the influence of the air. The particles in breaking are liable to break along lines of a cleavage in parallel planes, so that the particles are in the form of slivers or splinters, with little thickness and body. Conglomerate cemented together from a large number of small pieces should be prohibited, even if apparently hard. Such aggregates are not suitable for concrete, because the voids are likely to be excessive. Besides, the concrete will not pack so closely as concrete made with aggregates approaching a more cubical form, as mentioned on page 112. Crushed shale should not be used in reinforced concrete construction, as it frequently contains large quantities of rotten rock, which has little strength and is therefore not suited to such work.

Slate.—Broken slate is open to the same objections as shale though it is likely to be cleaner and freer from rotten rock. It is seldom used in concrete work, and would only be considered as an aggregate where the locality determines it to be the most available material. Crushed slate should not be used in reinforced concrete construction.

Broken Bricks.—Old bricks of hard quality furnish a cheap aggregate for concrete for many purposes when crushed. Broken brick for use as a concrete aggregate should be from well-burnt and perfectly sound and hard clay bricks. Care must be taken to see that they are not too soft. They should be of the size specified for broken stone (see page 113) and be free from old mortar and from dust or particles that will pass through a sieve of ⅛-inch mesh.

Burnt Clay Ballast.—Ordinary burnt clay ballast for use as a concrete aggregation should be free from lime and sulphur and from unburnt particles, and should be thoroughly hard. In other words, hard burnt clay should be made from suitable clay, free from sand or silt, burnt hard and thoroughly. Absorption of water should not exceed 15 per cent.

Shells.—In some localities there are large deposits of shells, which, mixed with sand and cement, make a good concrete. Tests of any such substances should be made to determine the best mixture and the strength.

Coral as an Aggregate.—While in Florida during 1908-9, the author observed that crushed coral made a satisfactory aggregate for concrete. This rock is found along the coast, being fragments from some large coral formation which is hard enough to have withstood the action of the sea and weather.

Pumice.—Pumice should be hard, free from all organic matter, soft dust or impurity, and show a bright silky structure when broken.

Art. 12. Water for Concrete

Water is the chemical agent which unites with the cement and results in that crystallization of the silicates which is commonly known as the setting of the cement. Most persons think that any kind of water is good enough for mixing concrete. However, the same care should be given to mixing water as is given to drinking water. In general, it may be said that water fit for washing will be suitable for concrete.

GENERAL REQUIREMENTS

The water used in mixing the concrete should be fresh, clean, free from acid, strong alkalis, oils, and organic matter in solution or suspension, and preferably "soft"—that is, free from mineral matter in solution. In other words, the water should be clean, "soft," fresh and neutral.

Pure Water.—The first consideration is *pure* water. Neither muddy water, stagnant water, water impregnated with alkali, nor water discolored by the refuse from factories, sewers, reduction-works or the like, will give the best results. If any doubt is entertained as to the purity of the water, it should be analyzed (see page 129) or given a practical test. Clear rain or river water is best, since water from wells or springs oftentimes contains acids or other chemicals likely to affect the cement. Water should by all means be free from mineral salts, which are detrimental to cement work. Fresh water may contain mineral matter in solution that will cause the water to have an injurious effect on the cement. Because water comes from an inland lake or stream is not proof positive that it is suitable. Its effect on the cement to be used should always be learned. The use of water strongly impregnated with lime weakens the strength of the concrete and should be avoided wherever possible.

Water that is to be used for concrete should also be free from iron or other impurities that tend to discolor the concrete. Any considerable percentage of iron in the water will have the effect of making the concrete a dark brown color after exposure to the air for some time. There is no known method of altering this appearance, except to give the concrete a coat of paint of the desired color.

Water should also be free from acids or strong alkalis. Water

which contains salts in solution in small quantities is suitable for concrete, but strongly acid or strongly alkaline water is doubtful and may be dangerous. Water in alkali country is always open to doubt. When working in sections of the country where there is considerable alkali, the water should be tested and should never be used if it contains alkali. Cement is chemically basic, and is therefore naturally active to a greater or less extent with the various acids. Alkalis in water may hasten the setting and hardening of concrete, but are ultimately detrimental to strength. If it is impossible to obtain other water within a reasonable cost, samples of the water should be taken to a competent chemist for analysis, in order to see whether the alkali contained is likely to be harmful to the concrete, as some of the salts known commonly as "alkali" are not harmful. If chemical tests are impracticable, then make practical tests in the field.

Water from streams into which manufacturing wastes are discharged is always open to doubt. In fact, such water should always be carefully examined. Water which runs from coal mines should not be used, as it usually contains free sulphuric acid and iron sulphate, and is not fit for cement work. Some river waters, especially of streams into which the waste of chemical and iron industries empty, will be found to contain injurious percentages of acids, usually sulphuric, and in some cases it is strongly alkaline.

The inspector should ascertain and report these facts to the engineer. If there is doubt as to the quality of water available, have it tested in a practical way by experts.

Clean Water.—The water used in mixing concrete should, above all things, be *clean* and especially free from injurious minerals and animal or vegetable matter. This is generally mentioned in the specifications, but is often ignored by the contractor. In other words, only fresh, clean water free from ashes and other impurities should be used. Dirty water will have the same effect as dirty sand or dirty gravel, weakening the concrete and in some cases retarding the setting. The effect of bad water in concrete construction may be seen in a number of places.

The presence of mud, oil, strong chemicals, slime, or other filth or pollution is impermissible. Water containing sewage sludge is very objectionable. If sewage sludge is present, it is apt to coat the broken stone or gravel and prevent proper adhesion between it and the cement.

The inspector should, in lack of specified directions, report these facts to the engineer. Water carrying in suspension considerable quantities of mineral or vegetable matter should be unconditionally rejected.

Use of Sea Water.—Sea water is objectionable for gauging concrete, not because of its saltness, but because of the presence of other salts which act upon the cement during the process of setting or hardening. This action of sea water on cement has exercised the minds of engineers for many years. The tendency to disintegrate that has been observed is purely the result of chemical action and

the formation of soluble salts, which possess an affinity for the aluminous element in the cement, forming expansive compounds of alumina. This is especially likely to occur if the cement used is high in alumina. The most injurious salt in sea water seems to be sulphate of magnesium, and the action that takes place when brought in contact with the cement is supposed to be somewhat as follows:

Magnesium sulphate in sea water reacts with lime in cement, forming calcium (lime) sulphate, precipitating magnesia; the calcium sulphate formed immediately recombines with the alumina in the cement to form aluminous calcium-sulphate, which is a gelatinous compound possessing expansive properties. The next result is, at any rate, the gradual "rotting" of the cement and the eventual failure of the concrete. This tendency to disintegrate may be checked to some extent by the use of cements relatively low in lime, alumina and sulphates, and by the adoption of a waterproofing process which will prevent the diffusion through the concrete of the active constituents of the sea water. An additional effect of sea water on cement is to increase the time required for setting.

Sea water should preferably not be used for mixing concrete, especially if it is desired to show no efflorescence (see Art. 31). In case it becomes necessary to use sea water, where pure water cannot be obtained, the latter may be used, but careful tests must be made at all times. Sea water should not be used with overlimed cement. Sea water must not be contaminated with sewage or manufacturing wastes, as is the condition in many harbors on our coasts.

Experiments have been made which showed corrosion of steel reinforcement in concrete mixed with sea water.

Use of Common Salt in Mixing Water.—Formerly common salt, or sodium chloride, was held to be injurious to the strength and permanency of the cement, but experiments have demonstrated that, in small percentages at least, it is harmless; indeed, by some regarded as beneficial, increasing the fireproofing of concrete. The ordinary occasion for adding salt is for the purpose of lowering the freezing point, thus permitting work to be carried on at a lower temperature, as discussed in Art. 33, page 351.

Temperature.—The temperature of the water used in gauging exerts a marked influence on the rate of set, which seems to vary directly with the rise from the freezing point, being practically nothing at 32° F., normal at about 65° or 70° F., and almost instantaneous at the boiling point. However, in actual construction, while at the temperatures between freezing point and 50° F. the set does not take hold as soon as if the temperature were in the neighborhood of 70° F., yet the heat generated internally by the incipient chemical action soon warms up the mass to a degree where normal rate of setting ensues. Hence, little attention need be given to the temperature of the water unless both it and the atmospheric temperature are around freezing point, when it is advisable to heat the water. (See Art. 33, page 355.)

Quantity of Water Required.—Considerations influencing the amount of water to be used are discussed in Article 15, page 193.

EXAMINATION OF WATER FOR CONCRETE

As natural waters vary greatly in composition, and as certain alkali salts affect concrete injuriously, chemical and physical tests made in advance is the only proper safeguard.

The suitability of water for concrete may be determined as follows:

Physical Appearance.—The water should be clear, tasteless and odorless. It should also be perfectly limpid, that is, no stickiness, oiliness or grittiness. Try it with soap—it should make a smooth, luscious lather. If the water meets these simple requirements or trials, it is satisfactory; if suspicious, it may be further examined as follows:

Acidity or Alkalinity Tests with Litmus Paper.—Acids or alkalis in water may be very easily detected by the use of paper treated with litmus, which may be procured at any chemist's. Litmus is a chemical which indicates acidity or alkalinity by a rapid change of color, responding even as a barometer does to a change in atmospheric pressure or a thermometer to the changes in temperature. Both red and blue litmus paper should be used. If the *blue litmus paper* remains blue on immersing in the water, then the property is either neutral or alkaline; if the color changes quickly to a red or a brown, then acidic, which will require the water to be further examined for its effect upon the setting qualities of the cement. Strong acids eat cement, while faint ones, especially the acid likely to be present in ordinary waters (carbonic acid), are practically harmless. In fact, carbonic acid is a real benefit, helping to convert the lime present in the cement into carbonates. In every case where the blue litmus paper turns red, the effect of the acid in the water upon the setting qualities of the cement should invariably be ascertained. Usually, with fresh blue litmus paper, if there is a dangerous amount of acid present, the change of color will be very rapid; if slow and faint, then it is fairly safe to assume that the amount of acid is negligible.

Let us suppose the water to have been tried with the *red litmus paper.* If the color changes very quickly to a blue, then strong alkali is indicated. If this is the case, the effect upon the setting qualities of the cement must again be learned. Alkalinity is in general less dangerous than acidity. In fact, alkalinity is the natural property of cement itself. Therefore, unless the indication is very marked, and is substantiated by other tests, especially by the effect upon the set, the indication may be disregarded.

In other words, if the resulting indication from the use of litmus paper is virtually neutral, that is, if it is faint for both the blue and the red litmus, then the water may be assumed fit for mixing concrete.

Boiling Test for Matter in Solution.—A definite quantity of water, either by weight or by volume, should be boiled to a residue, and the percentage by weight of the solid matter calculated. If in excess of 2 or 3 per cent, the water should be submitted to a competent chemist for analysis, and the nature of the matter in solution learned. In this case, a short effect on the setting qualities of the cement is not very

satisfactory, since ingredients may be present that will only develop unsoundness after considerable time. Less than 2 or 3 per cent of solid matter in solution may be disregarded, and if it is silt of fine grit, even greater percentages may be safely disregarded.

Effects upon Cement Pats and Briquettes.—The water may be tested by gauging a comparative set of pats and briquettes when testing the cement itself (see Art. 5). Any marked difference negatively will indicate unfitness. It must not be supposed that this indication is absolute, for the reason ingredients may be present in the water that will only develop unsoundness after considerable time, as stated above. However, this is the most positive test that can be made, and it will usually be safe to accept its fitness as final.

The water should invariably be tried for its effect upon the setting qualities of the cement, and also by making pats of a known-to-be-sound cement and noting its effect upon the soundness, using the boiling test to expedite matters if so desired. Any strong quality of unfitness will be sure to show in one or the other of these determinations.

CHAPTER III

INSPECTION OF PROPORTIONING AND MIXING CONCRETE

Art. 13.—Proportioning Concrete

It is not alone sufficient, in connection with the selection of aggregate, to examine the mineralogical nature of the aggregate to ascertain its hardness and density and freedom from loam and other impurities that would detract from its quality, but greater and more careful attention must be given to the volume and comparative grading. In other words, with the proper material selected, the next step is to properly proportion them so as to produce a concrete in which the mortar will fill all the voids, and, when rammed in place, free mortar will flush to the surface.

Proportioning is perhaps the most important and at the same time the least understood of the processes involved in concrete manufacture. A great deal of study has been given to the question of proportioning the materials of concrete, and most of the study has been directed to one end, viz., to find a mixture that will give the maximum density and strength with a minimum amount of cement. It is well known that with any given sand and broken stone or gravel, with a fixed quantity of cement, the mixture that gives the least volume will furnish a cement of maximum strength. Such a mixture is the densest obtained under the given conditions, and is obtained when the volume of cement, sand and water just fills the voids in the stone. The difficulties in arriving at any definite rules for obtaining this result arise from the great variation in the various elements affecting the work, no two materials being exactly alike, and rules deduced from one set of experiments being of very doubtful value when applied to other conditions.

Importance of Proper Proportioning.—It should be remembered that the strength of the concrete will depend on its density. A mixture of cement and sand, 1 to 3, will usually be found weaker than a 1 to 7 mixture, properly proportioned, of cement, sand and gravel or broken stone. Mixtures of cement and sand are greatly strengthened by the addition of a suitable amount of coarse material, though the proportion of cement is thus decreased. In other words, the proper proportioning of concrete materials increases the strength obtainable from any given amount of cement, and also the density or watertightness. By properly proportioning concrete, a great saving in materials can be effected. Lean mixtures can be used in heavy construction where the concrete is stressed only in compression.

Also, the richness of the mixture can be varied in different parts of the same structure, according to the nature of the stresses, reinforcement, etc. In fact, proper proportioning is very important for reinforced concrete so as to give the uniformity and homogeneity which cannot be obtained without careful attention to the proportions and grading of the aggregates.

It is, therefore, well worth while to give careful study to the concrete materials and their relative proportions which it is proposed to use.

Principles of Proper Proportioning.—The theory of proportioning the materials contemplates, fundamentally, the elimination of voids by so grading the sizes of material and so regulating the quality of each size that each will fill the voids between the particles of the next larger size. In a perfect mixture the cement would fill the voids in the sand and coat each grain, while the sand with its coating of cement would fill the voids in the aggregate and also cover each stone with a film of mortar. Such a concrete will be of maximum density for the given amount of cement. The density or water-tightness of concrete has been found to vary considerably by varying the proportions of the aggregates. Thus it will be seen that two well-established laws govern the theory of proper proportioning, namely:

1. *With the same percentage of cement in a unit volume of concrete, the strongest and most impermeable concrete is that which has the greatest density.*

2. *If the sand and stone remain the same, the strongest and most impermeable concrete is that containing the greatest percentage of cement in a unit volume.*

The first law is extremely important. Another way of expressing it is to say that, to obtain the greatest strength and impermeability, the cement should fill the voids of the sand and the resulting mortar should fill the voids of the stone. The second law means that with the same aggregates the strength and water-tightness increases with the amount of cement used—provided, however, that in some cases this amount be not in excess of the voids in the sand, and that the amount of mortar used in each case be the same. If the cement more than fills the voids of the sand, or if the mortar more than fills the voids of the stone, the concrete will be less dense than if the voids were just filled (ordinary concrete has a density between 0.80 and 0.88 and hence is denser than either neat cement or cement mortar); and thus the strength due to increase of cement *may* be offset by the decrease in density.

Limits of Refinement in Proportioning.—Although a good deal of care in proportioning is warranted, to obtain the best mix with any given material, too great refinement is unnecessary, and the theoretical methods which have been gone into with such great detail in many of the books on concrete work have more of an academic interest than a practical value. In other words, it does not do to go to too much expense in grading the concrete materials, but some

expense should be gone to in this regard, for the quality of the concrete obtained will pay for the extra work.

In practice it is impossible to fill all the voids in concrete. In the first place, the cement and sand cannot be perfectly distributed, and, in the second place, the water used in the mixing causes the sand to swell, thus increasing the voids about 10 per cent. This swelling is due to a film of water between the grains, and this film cannot be entirely displaced by the cement. When the water evaporates after the concrete has set, voids always remain throughout the mass, and some shrinkage of the mass occurs.

GENERAL REQUIREMENTS

In the proportioning of concrete the object to be aimed at should be to so proportion the fine and coarse materials that a given amount of cement will be as effective as possible in filling the remaining voids and binding together the particles of the aggregate. This requires that the proportion of voids be reduced to a minimum, avoiding, however, the use of much very fine material. Having a minimum proportion of voids, an amount of cement should then be used which will give the requisite strength or degree of water-tightness. (See Art. 47.) All voids in the aggregate should be filled.

Grading of Aggregates.—The sand should be well graded from coarse to fine, the coarse particles predominating, so that when mixed with the cement required will produce a dense and compact mortar (see Art. 8). The coarse particles should not exceed 1/4 in. in diameter. The advantage of grading is to minimize the voids and reduce the actual surface area of the aggregate to which the cement must adhere. This advantage applies with equal emphasis to the larger aggregate, such as broken stone or gravel. In other words, the aggregate should be well graded and should not contain an excess of one size particles and a small amount of fine particles.

Relation of Fine and Coarse Aggregates.—As stated above, the fine and coarse aggregates should be used in such relative proportions as will insure maximum density. In unimportant work it is sufficient to do this by individual judgment, using correspondingly higher proportions of cement (see page138). In other words, it is sufficiently accurate to select the proportion of cement to sand which will give the required strength to the concrete, and then use twice as much gravel or broken stone as sand. For important work these proportions should be carefully determined by density experiments as described below, and the sizing of the fine and coarse aggregates should be uniformly maintained, or the proportions changed to meet the varying sizes. It pays from an economic standpoint to make very thorough studies of the materials of the aggregate and their relative proportions, especially for important structures.

If the gravel is used without screening, it should be examined from time to time, and in case its composition is not such as to give the required proportions, sand or broken stone should be added as may

be necessary. Sometimes concrete is made of cement, sand, gravel and broken stone, the gravel being intermediate in size between the sand and the broken stone. Good dense concrete may be made of this combination if suitable proportions are determined.

The coarser the stone, the coarser the sand should be, or, for dense work, the sand can be graded from fine to coarse. When the aggregate used is of a small size, the sand should be fine to make dense work.

Relation of Cement and Aggregates.—The factor that determines the actual strength of concrete is most correctly the strength of the mortar or binding matrix, and, accordingly, the greatest care must be taken in the selection of the sand or finer aggregate, to contribute the maximum strength. The proportions of cement to sand and stone should be chosen after a very careful study of the local conditions and the available materials. For reinforced concrete construction a density proportion based on 1:6 should generally be used, i. e., 1 part of cement to a total of 6 parts of fine and coarse aggregates measured separately.

Concrete is sometimes made of sand and cement only, there being a large quantity of sand in proportion to the cement, say, 1 of cement to 7 or 8 of sand. This does not make good concrete. The voids in the sand cannot be filled by so small a proportion of cement.

Since cement is generally the most expensive ingredient, the reduction of its quantity, which may very frequently be made by adjusting the proportions of the aggregate so as to use less cement and yet produce a concrete with the same density, strength and impermeability, is of the utmost importance.

Determination of the Proportion of Cement.—The proportion of cement to be used depends upon the per cent of voids in the mixture of sand and gravel or broken stone. It also depends upon the purpose for which the concrete is required, the required water-tightness (see page 422), the character of the aggregates, and many other matters which must be considered in direct connection with the work to be done and the available materials. In general, it may be said that an amount of cement sufficient to fill the voids in the mixture will give a first-class concrete. A rich mixture is obtained when the cement is somewhat in excess of the quantity that would theoretically be sufficient to fill the voids in the sand. Often an amount of cement less than sufficient to fill the voids will produce a concrete of ample strength and satisfactory for the purpose, although somewhat porous. Greater compressive strength, however, may be obtained by increasing the proportion of cement.

Interpretation of Concrete Proportions.—When a specification requires, for instance, a 1:2:4 concrete, it should be understood that the strength of the binding matrix is to be equivalent to the strength of a 1:2 mortar, with a finer aggregate of a granulometric composition most perfectly adapted, consistent with practical conditions, to give the greatest strength. A very frequent mistake is made in the interpretation of a 1:2:4 concrete as equivalent to 1 part of cement

and 6 parts of inert aggregate entirely disregarding the volumetric composition. A typical instance may occur in the substitution of a natural mixed gravel on work requiring a 1:2:4 mixture. Frequently the contractor assumes the liberty of using six parts of gravel, ignoring the interpretation of a 1:2:4 specification as requiring the strength of a 1:2 mortar, and that correctly gravel should only be used in proportion so as to provide two parts of the finer aggregate. One local contractor, who was building a small bridge, insisted that a proportion of 1 of cement to 6 of gravel meant one sack of cement to six wheelbarrows of gravel.

Some time ago the author had occasion to examine some concrete foundation walls on a job where the concrete had proven unsatisfactory. The specifications called for a 1:3:6 mixture of cement, sand and gravel, respectively. The sand was a first-class one and the cement had passed all the requirements (see Art. 4), but the gravel itself contained almost enough sand to be used with the cement alone. There was an inspector on this job, but he was permitting concrete to be mixed in the proportions named above. What they were really getting was more like a 1:6:3 mixture. It is not difficult to see that the cement could not possibly have filled the voids in the sand. As a matter of fact, the resulting concrete was very deficient in strength and was condemned.

Proportioning Pit-Run Gravel Concrete.—In proportioning pit-run gravel concrete, frequent tests should be made to determine the proportion of sand to stone. To secure the necessary strength, the cement should be proportioned according to the amount of sand contained in the gravel, sand being defined as that part of the pit-run gravel (a natural mixture of sand and stone) which will pass through a 1/4-in. screen. The relative proportion of sand and stone in the gravel should be such that the volume of sand will not fall below, say, six-tenths of the volume of stone. This is the proportion adopted by the Illinois Highway Commission.* Any gravel, therefore, having a sand-to-stone ratio greater than 0.6 may be used without modification, but for gravel so used the cement-to-sand ratio should be constant for a given class of concrete. For example, three classes of concrete—known as Class A, Class B, and Class C—will be considered for illustrative purposes.

Class A concrete to consist of 1 part cement, 2 parts sand and 3½ parts broken stone (graded from 3/8 in. to 1 in. in size). Class B concrete to consist of 1 part cement, 2½ parts sand and 4 parts broken stone (graded from 3/8 in. to 1 in. in size). Class C concrete to consist of 1 part cement, 3 parts sand and 5 parts broken stone (graded from 3/4 in. to 2½ in. in size). Gravel may be used in place of broken stone and sand for concrete, and when so used should conform to the following requirements:

For Class A and Class B gravel concrete all material which passes a 1/4-in. screen should be considered sand, and all material which is retained on a 1/4-in. screen and passes a 1-in. screen should

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be considered stone. For Class C gravel concrete all material which passes a ¼-in. screen should be considered sand, and all material which is retained on a 2½-in. screen should be considered stone.

For any of the above named classes of concrete, should the volume of sand so found be less than 60 per cent of the volume of stone, sufficient sand should be added to bring up the proportion of sand to stone to 60 per cent. Should the volume of sand be more than 60 per cent of the volume of stone, sufficient stone should be added to reduce the proportion of sand to stone to 60 per cent, or sufficient cement should be added so that the volume of cement to sand will be for Class A concrete as 1 to 2, for Class B concrete as 1 to 2½, and for Class C concrete as 1 to 3. In any case, the proportion of cement to sand should be as stated for the various classes of concrete.

Experimenting with Different Proportions.—On any concrete construction work where sand and broken stone or gravel is stored and used, there is a certain proportion of one to the other in combination with a unit of cement that gives the strongest concrete using these materials. This combination, when made, will also be the densest and heaviest concrete attainable with these materials. It will generally be necessary to experiment with different proportions of varying sizes of sand and broken stone or gravel in order to ascertain the best mixture of the available materials at hand to secure the desired ends. That is to say, the desired combination to obtain this mixture must be made by trial, and, when found, these proportions should be specified and used. In other words, the proper proportioning of aggregates should be the occasion for careful experiment, and if the common materials at hand fail, as they will often do, to yield the required density, the deficiency must be supplied by importation of suitable amounts of the size or sizes lacking.

Accurate Proportioning.—The inspector should make certain that the specified proportions are accurately and uniformly adhered to. Any variation from these proportions must be with the written consent of the engineer. The inspector should constantly bear in mind that while splitting hairs is not warranted by the exactness of the process of concrete making as it is conducted in practical construction work, slipshod and careless methods or practices in proportioning the ingredients of concrete should not be tolerated. (See pages 150, 158 and 379.)

Dispute Regarding Quantities of Aggregates.—Should there be any dispute in regard to the quantities of aggregate to be used for each bag or barrel of cement, it should be decided by a test. However, do not split hairs on the mathematical proportions of the several materials which make up the concrete. This frequently causes a lot of squabbling with the contractor without any good resulting from it.

Changing Proportions of Concrete.—After the proportions have been established from time to time, they should not be changed during any period of twenty-four hours, unless the contractor desires to use materials of widely varying characteristics, and the proportions determined at any one time should continue to be used until the next

determination is made and the contractor ordered to change the previous proportions.

Methods of Proportioning.—It is recognized generally that for maximum strength a concrete should be as dense as possible, as mentioned above—that is, that it should have the smallest practicable percentage of voids. There are four methods in more or less general use in proportioning concrete, all aiming toward this result, which may be briefly designated as follows: (1) By arbitrary assignment; (2) by void determination; (3) by trial; and (4) by mechanical analysis of sieve-analysis curves. These methods will be considered separately in the above order.

PROPORTIONING BY ARBITRARY ASSIGNMENT

Proportioning is commonly done by rule of thumb, assuming the relations of cement, sand and broken stone or gravel as a matter of judgment, or using certain standard proportions, without much, if any, consideration of the character of the aggregate. This is the least scientific method of proportioning concrete, being frequently employed, regardless of whether the broken stone to be used is crusher-run, having sizes varying from 1/4 to 2 1/2 inches, and having 20 per cent voids, or whether it is screened to practically one size and has 50 per cent of voids. In other words, the practice has been to mix concrete by taking 1 part cement with certain parts of sand and broken stone or gravel, the proportions being assigned without any reference to the fineness or coarseness of the sand and the stone, or to the gradation of the sizes of each. Often concrete proportioned by this process can be greatly improved by substituting coarse aggregate for a portion of the sand, etc. This practice is gradually changing, however, in view of the fact that the best concrete is that in which the aggregate is uniformly graded from coarse to fine.

Unless the character of the materials to be used is known, and unless the qualities of the concrete made with certain proportions of the ingredients are known, proportioning by arbitrary selection of volume should not be employed. Better results with greater economy can often be secured by the use of more accurate methods of proportioning by the determination of voids (see page 139), by trial (see page 145), or by a mechanical analysis (see page 147).

Arbitrary Selection of Volumes Easily Misleading.—While the common custom of specifying arbitrarily the proportions of cement, sand and broken stone or gravel in parts by volume may be convenient in construction, this practice causes wide discrepancies in results because of different methods of measuring or proportioning the materials. A 1:2:3 mixture of one contractor may be identical with the 1:3:5 mixture of another, owing to differences in the sizes of sand and stone. In other words, a concrete called a 1:2:3 mixture by one man may not contain any more cement than a concrete termed a 1:3:5 mixture by another. Again, if a strong concrete is desired, a proportion of 1:2:4 may be adopted without any

consideration whether some other proportion of the same ingredients might not give a cheaper and also a stronger concrete. In view of this, it is preferable to abandon specifying mixtures as 1:2:3, 1:2:4, 1:2:5, but as 1:5, 1:6, 1:8, respectively, in which case the 5, the 6 or the 8 parts of aggregate are mixed up, reducing the voids to whatever figure is necessary for maximum density or strength, and then the cement added. Both methods of proportioning will be considered, since both methods are in use at the present time.

However, if the units of measurements and the methods of measuring are stated definitely (see Art. 14), proportioning by arbitrary selection of volumes may give good results in practice, although necessitating a much larger quantity of cement than more scientific proportioning would require.

Proportioning of Sand to Broken Stone or Gravel.—On work which will not warrant special tests and for which there is no choice of aggregates, the proportion of sand to broken stone or gravel may be taken as 1:2, which will be suitable under many conditions, depending, however, upon the character of material used. The relative proportions of the sand to the broken stone or gravel should vary as the work progresses and not be held exactly to a 1:2 ratio, governing the proportions by the way the concrete works into place. Harsh working of the concrete will be indicated by too much sand, while if there is too little sand, stone pockets are likely to occur on the surface of the concrete, making it difficult to fill the voids of the stone. Experience in the handling of concrete enables one to judge readily whether the mortar is deficient or not. An excess of mortar is preferable to a deficiency, as a concrete deficient in mortar is difficult to place and is especially to be avoided in reinforced work or work designed to be impervious.

The use of twice as much broken stone or gravel as sand, mentioned above, is based on the voids in the coarse aggregate, being from 40 per cent to 60 per cent of its bulk, with an average (which is suitable under many conditions) of 50 per cent. Concrete composed of one part of mortar to two of broken stone or gravel would therefore be about right. The volume will be practically equal to that of the coarse aggregate. This allows only sufficient fine material to grade down and fill the voids of the coarser grains. In cases where the coarse material contains a good many small particles, as does crusher run, broken stone or graded gravel, or the sand is so fine as to flow readily into the voids of the stone, the proportion of sand should be slightly less than half the volume of stone, since the cement increases the bulk of mortar and hence assists to fill the voids in the stone. In such cases the volume of the stone may be made equal to the cement plus twice the volume of sand. This would give a proportion of 1:2:5 as against 1:2:4 where screened broken stone or gravel is used.

As the voids in ordinary crusher-run broken stone, from which the fine material has been screened out, will range generally between 45 and 55 per cent, a proportion of one volume of sand to two volumes of broken stone will generally give but little surplus of sand unless

the mortar is quite rich. For ordinary sand, the proportions of mortar to broken stone, when various mortars are used and the sand is equal to one-half of the stone, are about as follows:*

Mortar	1:1	1:1½	1:2	1:2½	1:3	1:3½	1:4
Stone	2	3	4	5	6	7	8
Per cent of mortar to stone	72	61	55	52	50	49	48

For all proportions of 1:2, or poorer, the relative amount of mortar is closely equal to 50 per cent of the broken stone or gravel. For richer mortar the ratio of sand to stone may be reduced somewhat below one-half. For a 1:1½ mortar, for instance, the broken stone or gravel may be at least 3½ parts.

PROPORTIONING BY VOID DETERMINATION

A theoretically correct concrete should consist of sand and gravel or broken stone, or a combination of them, containing any amount of cement equal to the voids in such combination. To state this in another way, if the concrete is made up of sand and broken stone or gravel, such proportion of cement should be used with the sand as is equal to the voids in the sand, and such quantity of this resulting mortar of sand and cement should be used with the broken stone or gravel as will fill the voids in the broken stone or gravel. Restating this in a few words, the cement should fill the voids in the sand, and the resulting mortar should fill the voids in the aggregate. Therefore, to determine the best proportions for any sand and aggregate, find the per cent of voids in the sand and in the stone, and use enough cement paste to fill the voids in the sand, and enough mortar to fill the voids in the coarse aggregate.

However, in using this method it should not be overlooked that the use of cement paste equal to the voids in the sand does not insure that the voids of the sand are filled, and that the use of mortar equal to the voids in the broken stone or gravel does not insure that the voids of the broken stone or gravel are filled. The cement paste surrounds the sand grains and virtually increases the size of all the grains, and thereby increases the voids, since there are then no small grains to occupy the interstices between the larger ones; and, further, the water in the paste, by its superficial tension, keeps the sand grains apart and thus increases the per cent of voids. A similar effect occurs when mortar is mixed with the broken stone or gravel.

The method of proportioning a concrete with reference to the voids is objectionable, since the per cent of voids in the sand may be greatly affected by a small per cent of moisture, and also owing to possible errors in determining the voids by a direct measurement by the use of water. However, this method is more scientific than by arbitrary selection of the proportions mentioned above, and is more simple but less scientific than either by proportioning by trial, as mentioned on page 145, or by mixing the aggregate and cement according to a given mechanical analysis curve as mentioned on page 147.

*American Civil Engineers' Pocket Book, page 428, edition of 1911.

Determination of Voids in Aggregates.—The proportion of voids may be approximately determined in either sand, broken stone or gravel in the following ways:

Fill a vessel of known capacity with the material and then pour in all the water the vessel will contain. Measure the volume of water required and divide this by the volume of the vessel. The quotient represents the proportion of voids or expresses the percentage of voids. In other words, the volume of voids is determined by filling a vessel, whose cubic contents are known, with aggregate, then adding water until the surface of the water coincides with that of the aggregate. The volume of the water poured into the vessel is the volume of the voids in the material. Some experimenters start with the aggregate thoroughly wet, others with it dry. It seems to the author that the aggregate should be thoroughly wet before measurement, in order that its condition shall be representative of that found in actual concrete mixing. The wet aggregate gives the more accurate result; but there is no harm in using the dry method, which gives a little greater "factor of safety." In other words, the dry method allows a little larger factor of safety.

The following is a modification of the above method for determining voids in aggregates: Fill a vessel with the aggregate and let net weight equal B. Add water slowly until it just appears on the surface, and weigh. Let net weight equal A. Fill the same vessel with water and let net weight equal C. The percentage of void will then equal $100\,(A - B) \div C$. A vessel of not less than ½ cu. ft. capacity should be used. The larger the vessel, the more accurate the result.

A good method of determining the voids in concrete materials is to fill a box of exactly 1 cu. ft. capacity, or a convenient fraction thereof, with the substance, and weigh the contents. A solid block of quartz or limestone, measuring exactly 1 cu. ft., would weigh 165 lbs.; a cubic foot of sand, broken stone or gravel, considerably less than the latter amount; and the difference will represent the voids. In other words, the percentage of voids in the different aggregates may be determined by dividing the weight per cubic foot by the weight of a cubic foot of the solid material, subtracting the quotient from 1, and multiplying by 100. For example: If a cubic foot of dry gravel is found to weigh 96 lbs. (when settled by tamping or rapping the sides of the box), then the percentage of voids equals

$$\left(1 - \frac{96}{165}\right) = 100 = (1 - 0.58)\ 100 = 42 \text{ per cent.}$$

If the gravel weighs 106 lbs. per cubic foot, the percentage of voids will be 36.

Sand and gravel contain from 30 to 50 per cent of voids, while the voids in broken stone range from 40 to 55 per cent.

Proportioning by Void Calculations.—Mixed materials, which contain the greatest variety of sizes from fine to very coarse, will be found to have the least voids. With any two materials, one fine and one coarse, there is one mixture, and only one, which will give the

greatest possible density. This may be determined by calculation; for example, taking the gravel given above, since it contains 42 per cent voids, these must be filled by adding sand to the amount of 42 per cent of its volume. For this, 42 measures of sand to 100 measures of gravel will be required, or 1 to 2 1/3. For the broken stone, 40 to 55 measures to 100 will be required; or for broken stone containing 50 per cent voids, 1 to 2 measures will be required—that is, one of sand to two of broken stone. With mixed materials, such as are generally met with in practice, in which no sharp division between sand and gravel can be made, practical test will be found more satisfactory than calculation as described below. The sand and gravel or broken stone should be mixed in the calculated proportion, and also in other proportions, and the weight per cubic foot of each mixture taken until that giving greatest density is found. With favorable materials it will be found possible to make a mixture weighing 140 lbs. per cubic foot, corresponding to 15 per cent voids. If the greatest weight obtainable is less than this, the materials are not the best.

Proportioning with Reference to the Coarse and Fine Aggregates.— Concrete may be proportioned by the determination of voids in the broken stone or gravel and in the sand, and proportioning of materials so that the volume of sand is equivalent to the volume of voids in the broken stone or gravel and the volume of cement slightly in excess of the voids in the sand.

This may be done by making a box two feet wide, five feet long and one foot deep, of two-inch tongued-and-grooved plank, white-leaded or properly caulked in the seams so it will not leak (see page 204). Fill this box level with the largest aggregate (broken stone or gravel). Then pour into it slowly and carefully water from cans of definite size. When the box is full the amount of water in cubic feet represents the per cent of voids in the broken stone or gravel, because the box contains exactly ten (10) cu. ft. Empty the box and spread the stone on a platform. Measure out sand that will represent the voids found in the broken stone or gravel and mix the sand and stone together, then fill the box with the mixture. After this is leveled off, pour in water, carefully measuring it as it goes in, and the amount of water will represent the voids in both the sand and coarse aggregate. If this does not exceed 10 per cent, it will represent the amount of cement required, but if it exceeds 10 per cent, then some fine sand or screenings should be used to fill part of the voids. Density is wanted, and the most dense concrete is obtained when the materials are graded in size as mentioned above.

The following is a modification of the above method and may be used by those who do not care to construct the rectangular box of tongued-and-grooved stuff as described. Take a water-tight barrel and bore a hole in the bottom. In this fit a long wooden plug or stopper. Fill the barrel with the broken stone or gravel, and then pour in water until it overflows; draw the water off in buckets and measure carefully. The quantity of water represents the voids between the coarse aggregate to be filled with mortar. Now empty out the broken

stone or gravel from the barrel; pour back the water and mark the level on the side; then draw the water off; fill with sand to the mark, and this will determine the amount of sand to be used. Lastly, pour in enough water to come up to the level of the sand, and the amount used indicates how much cement is needed to fill the voids in the sand. To the above proportion of sand and cement add respectively ten (10) per cent, and the correct amount of cement, sand and broken stone or gravel will have been found. Sometimes, in addition to adding 10 per cent more cement than the voids in the sand, 10 per cent more sand than the voids in the broken stone or gravel is added to provide for inaccuracies in measuring the voids.

Proportioning with Reference to the Coarse Aggregate.—Concrete may be proportioned by the determination of the voids in the broken stone or gravel, and, after selecting the proportions of cement to sand, by test or by judgment, proportioning the mortar to the broken stone or gravel, so that the volume of mortar will be slightly in excess of the voids in the stone. In other words, by this method the voids in the coarse aggregate are determined and an amount of mortar then used, of the desired strength, sufficient to fill the voids. To insure this requires some excess of mortar, but this excess should be as small as practicable, since it increases the cost without increasing the strength.

In this method of proportioning, the ratio of cement to sand is first decided on; as, for example, a 1:3 mixture (1 part of cement to 3 of sand). A certain volume of broken stone or gravel similar to that which it is proposed to use in the concrete is put in any vessel, as a barrel of known capacity. Water is then poured on until the vessel holds no more, and this water, which has filled all the voids in the broken stone or gravel, is then run off and measured. The ratio of the volume of water to the entire volume of the vessel gives the proportion of the voids. Now, the mixture of the sand and cement, which is assumed to have the same volume as the sand alone, must fill the voids in the broken stone or gravel. Suppose, for example, that 40 per cent of voids are found for the coarse aggregate; it is usually customary to add 10 per cent for inaccuracy, so that, in this case, the voids are 50 per cent of the whole volume. Therefore, 50 per cent of sand must be added to fill the voids, and, consequently, the ratio of the volume of sand to that of the broken stone or gravel is 1:2 or 3:6. Therefore, the proper proportion of the materials for the concrete under consideration would be 1:3:6 (1 part cement, 3 parts sand, 6 parts coarse aggregate). This method of proportioning concrete is not very accurate and is complicated. The author would recommend that it be not used at all, but, if it is used, that it be left to a concrete specialist.

Proportioning with Reference to Graded Mixed Aggregate.—Concrete may be proportioned by mixing the sand and broken stone or gravel and providing such a proportion of cement that the paste will slightly more than fill the voids in the mixed aggregate. This is a more exact method than the one just mentioned above. The aggregates are first graded, both coarse and fine, so as to reduce the voids

in the mixture to a minimum. The proportion of aggregates having been determined, the amount of cement required will then depend upon the strength needed or the degree of imperviousness. An amount necessary to fill the voids can be estimated by determining the per cent of voids in the mixture of aggregates, well compacted or settled by shaking. If a concrete of maximum density be desired (see page 421), then an amount of cement should be used slightly in excess of that necessary to fill the voids. For this calculation the cement paste may be assumed equal to the volume of cement used, on the basis of 3.8 cu. ft. per barrel.

Proportioning with Reference to Trial Mixed Aggregate.—Concrete may be proportioned by making trial mixtures of materials in different proportions to determine the mixture giving the smallest percentage of voids and then adding an arbitrary percentage of cement, or else one based on the voids in the mixed aggregate. This method of finding the proper mixture of sand and broken stone or gravel is based on the fact that, other things being equal, the denser the mixture, the stronger will be the concrete. The operation is that of finding the mixture that has the maximum weight for a given volume. An ordinary galvanized iron pail and spring balances may be used for the purpose. The bucket is filled half full of water, and a batch of the sand and broken stone or gravel as a trial proportion is thoroughly mixed and slowly dropped from a shovel. The surplus water is allowed to flow over. Without tamping, the bucket is filled level full. The mixture that weighs the most will give the densest and strongest concrete, and, on account of having the least percentage of voids, it will require the least amount of cement.

Gravel Containing Sand.—When gravel containing considerable quantities of sand is used, several trials should be made to determine the proportion of sand it contains that will pass through a No. 4 screen (four meshes to the inch), and a corresponding deduction should be made from the sand used in making the mortar, so that the final proportions of the cement and sand in the complete mixture shall be as specified for mortar. Only the gravel remaining after screening out the sand should be treated as aggregate during the experimenting for voids referred to on the several succeeding pages for the four different methods of proportioning by void determinations. The author is in favor of separating the gravel into as many parts as is consistent with economy for the work in hand. Even on small work he believes it preferable to screen the gravel and remix it in the specified proportions.

Aggregates Composed of Broken Stone and Gravel.—When the aggregate is composed of both broken stone and gravel, they should be mixed in such proportions (to be determined by experiments as above mentioned) as will give the least per cent of voids when mixed.

Proportion of Mortar to the Aggregate.—The proportion of the mortar to the aggregate should be such that it will a little more than fill all the voids of the aggregate, the strength of the concrete de-

pending a great deal on the proportion of sand to the cement. Care should be taken to see that the proportions are such that the mortar will fill all the voids in the aggregate, and the mass will tamp solid. In general, the amount of mortar mixed with the aggregate should be at least 10 per cent more than the voids in the loose aggregate, which should be determined by experiment. The proportion of cement and sand to the aggregate depends a great deal on the nature of the aggregate; if it is of coarse stone with large voids, then it will require more mortar to fill them than if the aggregate was of a fine stone or gravel.

Proportions of Cement and Sand in Mortar.—The yield of mortar from a given sand should be separately determined in most of the experiments mentioned above. That is to say, the amount of mortar made by a given amount of cement and sand should be determined by experiment, but in the absence of such experiments, for general purposes the following may be used as an approximation, the units of cement being of 380 lbs. net for Portland and 265 lbs. net for natural cement:

	Portland Cement.			Natural Cement.		
Proportions	1 to 1	1 to 2	1 to 3	1 to 1	1 to 1.5	1 to 2
Cement, bbls	1	1	1	1	1	1
Sand, cu. ft	3.5	7	10.5	3.5	5.25	7
Resulting mortar, cu. ft	6	8	10.7	5.7	6.9	7.8

Definite Proportions.—In all void determinations the proportions to be used should be reduced to such a basis that they can be stated as follows, in terms of the actual materials as delivered on the ground for use: One bbl. cement to .... cu. ft. sand to .... cu. ft. gravel or .... cu. ft. broken stone. The proportions of the ingredients are usually stated with reference to the amount of cement to be used, it being taken as unit.

Description of Experiments, Approval, Etc.—The proportions so stated, together with the descriptions of all experiments leading thereto, should be submitted to the engineer for approval, and after approval must be followed in measuring the materials until there is reason to change them through change in condition of materials received. The necessity for such change should be determined by the inspector and approved by the engineer.

Adjusting Proportions of Aggregate.—The relative proportions of sand and coarse aggregate should be adjusted periodically, based on determination of the voids in the materials used in mixing the concrete.

Cost of Work Governed by Proportions of Concrete.—If the proportions as stated in the specifications are not suitable for the broken stone furnished, the engineer should determine the proper proportion. If the change in proportion alters the cost of the concrete, the difference should be paid for or deducted, as the case may be.

Tests of Voids as Work Progresses.—Tests of the voids in the aggregate should be made from time to time under the direction of the engineer and instructions given as to the per cent of mortar of the specified composition to be used. No extra allowance should be made to the contractor for such tests.

PROPORTIONING BY TRIAL MIXTURES

Concrete may be proportioned by making volumetric tests or trial mixtures of concrete with a given percentage of cement and different aggregates, and selecting the mixture producing the smallest volume of concrete; then varying the proportions thus found, by inspection of the concrete in the field. The principle of this method is that a combination of sizes of sand and broken stone or gravel which with a constant quantity of cement gives the least volume of concrete is the best.

This is the common-sense method of proportioning concrete, and is valuable as an easy and practicable means of determining the right proportions in which to combine natural mixtures of a sand and an aggregate; but it is impracticable for an exhaustive study to find the very best proportions attainable by screening the sand and the stone and making artificial combinations of the several portions. However, this method is sensible, because the materials at hand must be used and no expense be incurred in screening and separating in order to make exact proportions.

In proportioning by trial mixtures the proper proportions of sand and broken stone or gravel may be determined by finding what mixture has the maximum weight for a given volume, as follows: Use an ordinary galvanized iron pail and a spring balance. Mix several batches of different proportions, using full pails of material in each instance, as small batches are likely to prove deceptive. The sand and broken stone or gravel should not be mixed in a conical pile, owing to the likelihood of the coarse aggregate rolling away and being either ignored or taken in excess. Instead, use a flat bed in mixing. The mixture of sand and coarse aggregate should not be rammed into the pail, as it is almost impossible to ram twice alike. Instead, fill the pail about half full of water and sprinkle the mixture of sand and coarse aggregate into it slowly from a shovel. The pail should be filled in each instance, allowing the excess of water to run over the edge.

The combination of proportions having maximum weight should be used for all classes of concrete, using less cement for poorer mixtures. To determine the best proportion of cement, use the predetermined combination of sand and stone and mix different batches with varying proportions of cement. The concrete thus produced should be mixed to the consistency intended to be used in the work and carefully rammed or puddled into the pail until it is level full. The combination giving the greatest weight is the ideal one for that consistency of concrete selected, but more or less cement may be found advisable under various circumstances. If water-tight concrete is desired (see Art. 47) more cement must be used in each batch. If poorer grades are advisable, less cement may be used in the regular batch. Small variation in proportions of all the ingredients from the maximum will be found to make little difference in the resulting weights. It should be remembered that each batch of concrete must be weighed and taken out of the pail before it has time to set, as otherwise some difficulty might be experienced in getting it loose.

A modification of the above method consists in determining the proportions of concrete which will give the least depth in a given vessel, by varying the different proportions of sand and stone, but keeping the quantity of cement and the plasticity of the concrete the same in each case. To apply this method, procure a vessel of uniform cross-section, say, a cylinder 10 or 12 in. in diameter and 12 or 14 in. deep, and capped at one end. The strength of the cylinder should be such that its volume will not be changed in tamping it full of concrete. The pail as used above will not answer in this case, owing to not having a uniform cross-section. A cubical box with 12-in. sides may be used instead of the cylinder, if so desired. Weigh out a unit of cement, and any number of units of sand, say two, and also weigh out any number of units of broken stone or gravel, say four, taking care that the quantities are such that when the ingredients are thoroughly mixed and placed in the cylinder or in the box, the mixture will fill it only partly full, say three-quarters full. Make a concrete of any desired consistency by mixing the cement, sand and broken stone or gravel with water on a sheet of steel, and tamp or puddle the concrete into the cylinder or box leaving the upper surface smooth and horizontal, and then measure the depth of the concrete from the upper end of the cylinder or box. Next empty the concrete before it sets, clean out the cylinder or box and the tools, and make another batch of concrete with different proportions of sand, broken stone or gravel, but keeping the quantity of cement and the consistency of the concrete the same as before. If this batch, when tamped into the cylinder or box, gives a less volume of concrete, this proportion is better than the first. Various other mixtures of concrete should be tried in the same manner until the proportions have been found which will give the least depth in the cylinder or in the box, as the case may be. The proportions can be varied almost infinitely by screening the sand and the stone, and trying different combinations of the several portions.*

Carefully noting whether the height of concrete in the cylinder or box is more or less than the height of the first batch, will serve as a guide to further similar mixes, until a proportion is found which gives the least height in the cylinder or box, and at the same time works well while mixing and looks well in the cylinder or box, all the broken stones or gravel being covered with mortar.

Principles to Be Observed in Selecting Proportions.—The following principles will serve as a general guide in selecting the proportions to be tried with different mixtures in proportioning concrete by the above methods:

(1) The larger the maximum size of the aggregate, the denser and stronger the concrete. It is not practicable, however, to use larger fragments than 3/4 to 1 in. in reinforced concrete or 2½ to 3 in. in plain concrete (see page 113).

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* For the results of a series of trials to determine the density of various combinations of broken stone screened to several sizes, see *Engineering News*, Vol. 54, pages 598-601.

(2) The greatest density will be obtained with an aggregate graded nearly uniformly from fine to coarse.

(3) An excess of fine or medium sized particles decreases the density and also the strength of the concrete.

(4) The finer the stone, the finer should be the sand; and, vice versa, the coarser the stone, the coarser should be the sand.

(5) The density and also the strength of concrete is affected by the variation in the diameter of the particles of sand more than by the variation in the diameters of the stone particles.

PROPORTIONING BY SIEVE-ANALYSIS

The most scientific method for proportioning concrete is that known as the Mechanical Analysis. In fact, the only practical method of determining the best possible artificial mixture of sand and stone is by the use of sieve-analysis curves. This method of proportioning the sizes of the sand and stone in concrete was devised by William B. Fuller and is described by him in considerable detail on pages 183-215 of Taylor and Thompson's "Treatise on Plain and Reinforced Concrete" (1909 edition), to which the reader is referred, and also to Prof. Ira O. Baker's "Masonry Construction," pages 147-154 (1909 edition).

Proportioning by sieve-analysis is the most exact and effective method of studying the character of the aggregate and of calculating the effect of various mixtures. In other words, this method affords a means of determining the best proportions in which to mix the fine and the coarse aggregate, and also shows how the aggregate may be improved by adding or subtracting some particular size. In this method the available materials, including the cement, are separated into various sizes by means of a series of sieves, and the results plotted on cross-section paper, the percentage by weight passing each size sieve being plotted as abscissæ, and the size as ordinates. The curves thus plotted indicate the percentages of the whole mass that pass the several sieves. From a study of these curves the proportions of the different ingredients are determined, being combined in the proportions indicated by the sieve-analysis curves. A straight line indicates a uniform grading of size. The following sizes of screens are desirable, although a very useful analysis may be made with fewer screens: 3-in., 2¼-in., 1½-in., 1-in., ¾-in., ½-in., and ¼-in. (See page 101.)

Sieve-analysis can be made from time to time as the work progresses, to determine whether or not the sizes of the aggregate have changed; and if sizes have changed, the proportions can be varied to secure the most economical and densest concrete. As to whether or not the increased cost of screening and proportioning would be justified by the saving of cement, depends upon the magnitude of the work and other conditions. In a work of any magnitude this method is likely to be justified by the better quality, or the less cost, of the concrete secured; and the extra labor required to make sieve

analysis during the progress of the work will be worth all it costs because of the better control of the proportions of the concrete. This method is, however, not available in the usual course of concrete work.

PROPORTIONS FOR DIFFERENT CLASSES OF WORK

The concrete should consist of 1 part cement, 2 to 4 parts of sand, and 4 to 10 parts of broken stone or gravel measured by loose volume. For general purposes it is possible to state approximate proportions only, as the sand, broken stone, and gravel vary in size and proportions of voids according to their source and preparation. Those commonly used vary from about 1:2:4 to 1:3:6 of cement, sand and broken stone or gravel, respectively. In many cities the building laws determine the proportions to be used. The proportions should vary to suit the character of the work and the requirements which the concrete must meet.

The following list is presented to be used as a rough guide to the selection of proportions for different classes of work. These proportions have been adopted by practice, tentatively, in so much as it has been found that in general they give the desired results. These customary proportions or any or stated proportions should not be mistakingly adopted or religiously adhered to; instead, they may be misleading, and strict adherence to them, as is often blindly insisted upon by some overly zealous inspectors, may defeat the very object intended. A mere statement of proportions is no guarantee of quality. The proportions depend upon the character and size of the materials themselves. For any given materials the most economical mixture is in general the strongest. The best concrete can only be obtained by consideration of each particular case along the lines already indicated. For large and important operations a careful study of the materials and of the best proportions to use for economy and strength should invariably be made. In other words, the proportions must be adapted to the character of the work in which the concrete is to be used and the strength required. It is not always necessary to use the strongest concrete, as the concrete may be required to withstand only slight stresses and be simply used for its weight. The strongest concrete would then be unnecessarily expensive.

Rich Mixture.—In columns and other structural parts subjected to high stresses or requiring exceptional water-tightness, rich mixtures should be used in proportion of 1:4½, i. e., 1 part of Portland cement to 1½ parts of sand to 3 parts of coarse aggregate measured separately.

Standard Mixture.—In reinforced floors, beams, girders and columns, in arches, in reinforced engine or machine foundations subject to vibrations, in tanks, sewers, conduits or other water-tight work, standard mixtures should be used in proportion of 1:6, i. e., 1 part of Portland cement to 2 parts of sand to 4 parts of coarse aggregate measured separately. This mixture is used more than

any other, and richer mixtures than this are not common. It is also one that has been up to this time the most frequently used in tests of reinforced concrete structural members. This mixture may be considered as good, strong concrete as practically need be used for any piece of Portland cement concrete of appreciable bulk.

Medium Mixture.—In ordinary machine foundations, retaining walls, abutments, piers, thin foundation walls, building walls, ordinary floors, sidewalks and pavements, and sewers with heavy walls, medium mixtures should be used in proportion of 1:7½, i. e., 1 part of Portland cement to 2½ parts of sand to 5 parts of coarse aggregate measured separately. This mixture may be considered as giving a concrete of sufficient strength, when of proper dimensions, for any ordinary masonry construction, and, at many times and places, ample for very heavy work.

Lean Mixtures.—In unimportant work in masses, in heavy walls, in large foundations supporting a stationary load, in backing or filling for stone masonry, in foundations for asphalt pavements, and for similar purposes, lean mixtures should be used in proportion of 1:9, i. e., 1 part of Portland cement to 3 parts of sand to 6 parts of coarse aggregate measured separately. This mixture may be considered as giving a concrete of sufficient strength, when of proper dimensions, for much ordinary plain work in favorable positions.

Such proportions as 1:3:7, 1:4:8 or even 1:5:10 could be used where strength is not an essential characteristic. Included in the volume of the concrete masonry there could be large stone, say a foot or so across (see Art. 34, Rubble Concrete). These rubble stones should be separated from each other and from the surface. Mixtures as lean as 1:3:9, 1:4:12 and 1:6:12 are also used, but they are excessively stony and have a very limited application, mostly for filling purposes where a porous concrete having some coherency is desired.

Proportions for Natural Cement Concrete.—For natural hydraulic cement concrete, a good mixture of 1 part cement, 1 part sand and 2 parts broken stone or gravel may be considered as good, strong concrete as practically can be made with natural cement; and 1 to 2 or 4 to 4½ may be considered as poor and weak concrete as practically should be made with natural cement to be used in any work to be classed as durable and sufficient for loads usually placed upon masonry of ordinary dimensions.

Usual Proportions.—The usual proportions, unless otherwise particularly shown upon the drawings or called for by the specifications applying to the particular piece of work, should be: Plain or massive concrete: One (1) part Portland cement, two and a half (2½) parts sand, and five (5) parts broken stone or gravel. Reinforced concrete: One (1) part Portland cement, two (2) parts sand, and four (4) parts broken stone or gravel. The proportions vary with the strength required. The most economical proportions can be determined only by varying the proportions of sand and coarse aggregate and studying the result.

Cinder Concrete.—Cinder concrete may be composed of 100 lbs.

cement, 2 cu. ft. gravel or coarse sand, and 6 cu. ft. of cinders.

Slag Concrete.—Slag concrete may be composed of 100 lbs. cement, 2 cu. ft. gravel or coarse sand, and 6 cu. ft. of slag.

Determination of Concrete Proportions for Work in Place.—For an interesting account of a method of determining the proportions of a concrete after it has set in place, see *Engineering News*, Vol. 59, page 46, January 9, 1908.

Art. 14.—Measuring and Estimating Ingredients for Concrete

Methods of measurement of the proportions of the various ingredients, including the water, should be used, which will secure separate uniform measurements at all times. The proper amount of the several kinds of material should be measured in some way which is entirely satisfactory to the engineer or inspector in charge of the work, so that they may be satisfied that the requisite proportions of each kind of material are delivered for each batch of concrete.

UNITS OF MEASUREMENT

The proportions of the ingredients for concrete are usually stated in parts with reference to the amount of cement to be used, it being taken as unity, as, for example: Cement 1 part, sand 2 parts and broken stone or gravel 5 parts. The unit by which the parts are to be measured should be stated, otherwise confusion and misunderstanding will be likely to arise. In other words, if the units of measure are not stated in the specifications the inspector should see that a definite understanding is had by both engineer and contractor of what they shall be. Concrete may be proportioned or the ingredients measured in any one of three ways: (1) by weight; (2) by volumes of *packed* cement, loose sand, and loose stone; or (3) by volumes of *loose* cement, loose sand, and loose stone.

Measurements by Weight.—Concrete should, as a rule, be proportioned by weights, which is the most accurate method. Only occasionally, however, is this method employed, it generally being cheaper to use more cement than to incur the increased expense of weighing the ingredients. Cement should invariably be measured by weight, even if the sand and stone are not. In practice this is accomplished not by weighing on scales but by counting packages, since bags or barrels of cement have standard weights as mentioned below.

Automatic weighing machines are occasionally employed for measuring the ingredients for concrete as described on page 157.

Measurements by Volume.—This is the most common method of proportioning. When stating the proportions by volume, too much stress cannot be laid upon the necessity for the adoption of a standard unit, and upon distinctly specifying this standard, as otherwise an unscrupulous contractor may adopt for his unit the volume of cement very loosely measured, and thus produce too lean a concrete, as fully explained in the next paragraph. In other words, the volumes of sand and stone or other aggregate should be distinctly

stated in the proportions, in terms of the number of cubic feet of each material to a barrel of cement, or else by parts, coupled with the explanation that one part, or barrel, represents a definite volume. In specifications where the proportions are given by parts, with no unit of measurement, the contractor undoubtedly has the legal right to base the volumes of aggregate on the loose measurement of cement, and hence the necessity of exact statement of units as described below.

Volume of Barrel of Cement.—If the unit of measurement be the barrel of cement there is likely to be some misunderstanding, owing to the variation in the size of barrels and the degree of compression used in packing the cement in the barrel. In other words, cement is different in volume when measured loose and when packed in the barrel; cement barrels vary in volume of contents. In fact, the difference between the volume of a barrel of cement when measured packed and loose, and variations in size and weight have been subjects of extended controversy and often bitterness between engineer and contractor, and has resulted in much friction and litigation. It should be definitely understood by engineer, contractor and inspector: (1) whether the volume of cement used is its volume measured loose or its volume as packed in the barrel; (2) what the cubic contents of a barrel of cement shall be called.

The volume of a packed barrel of cement ranges from about 3.2 to 4 cu. ft.; when the cement is removed from the barrel it increases in volume between 20 and 30 per cent, being swelled considerably as it falls from the barrel. It is now customary to assume a barrel of packed Portland cement to be 3.8 cu. ft. If the barrel in which the cement was packed is used to measure the sand and stone, a mixture of 1:2:5, for instance, will mean one barrel or about 3.8 cu. ft. cement, two barrels or about 7.6 cu. ft. sand, and five barrels or about 19 cu. ft. stone. If the cement is removed from the barrel and the volume of the loose cement is taken as the unit of measure, the proportions 1:2:5 will mean about 9.6 cu. ft. of sand and about 24 cu. ft. of stone, making a weaker mixture than was contemplated, hence the necessity of exact statement of units as mentioned above.

Volume of Bag of Cement.—When cement was usually shipped in a barrel and a fractional part of a barrel was used for a batch of concrete, the cement was measured loose, but at present this method is not employed (except with automatic measuring machines), because it is simpler to consider the bag of cement as the unit, four of which are equivalent to a barrel of Portland cement or three of natural cement. In fact, the contractor's unit of measurement of cement is the bag. Contractors universally count one bag as being equal to 1 cu. ft., and many engineers specify this figure. It is the most convenient unit of measure in actual construction work, and for this reason and because of contractors' practice, the author would urge its adoption as standard practice. In other words, it is now the custom to assume that a bag of cement contains one (1) cu. ft., and the proportions 1:2:5 means cement 1 cu. ft., sand 2 cu. ft., and stone 5 cu. ft. In fact, it is very convenient to take the cubic

foot as a unit and consider the bag as containing 1 cu. ft. of loose cement.

Volume of Barrel of Stone.—If the sand and stone are measured in empty cement barrels, the inspector should have it understood whether a barrelful is the volume measured with the heads knocked out or the volume contained between heads; there is 3/4 cu. ft. difference.

Volume of Wheelbarrow Load.—Concrete may be proportioned by using a wheelbarrow for a unit of measure and mixing together the specified number of barrows of each material. If the materials are measured in wheelbarrows, the inspector should have it definitely understood what the volume of a wheelbarrow load shall be called; there is a cubic foot difference between the capacity of a wheelbarrow, water measure, and the load usually carried by men in wheeling.

Summary.—The unit of measure should be the cubic foot. The unit of measurement for cement should be the bag as received from the manufacturer, having a gross weight of not less than 95 lbs. (for Portland or natural cement). Such a packed bag may be considered as being equal to one (1) cu. ft. of cement. Cement lighter than above should be counted of proportionately less volume. The weight of cement is sometimes assumed as 100 lbs. per cu. ft., and the corresponding volume of a barrel as 3.8 cu. ft. or 0.95 cu. ft. per bag.

MEASUREMENT OF MATERIALS

The careful measurement of every batch of concrete is a matter of great importance and should never be neglected. Too much attention cannot be paid to this important part of concrete-making, for the only proper way to make concrete is by carefully measuring the proportions of cement, sand, broken stone or gravel. If properly managed it takes but little time and adds almost nothing to the cost of the work. All parts should be actually measured. No "guess-work" should be allowed. The materials should be measured loose in a uniform manner, easy to control either by workmen or superintendent, without likelihood of frequent error. In other words, the inspector should see that a method is adopted whose accuracy can be readily verified and which is sufficiently simple for the ordinary workman to carry out without likelihood of frequent error. Fine and coarse aggregate should be measured separately as loosely thrown into the measuring receptacle.

Where indefinite measures are used, inaccurate measurement is apt to come back on the contractor, because a careful inspector requires measurement on the safe side, and too little sand, broken stone or gravel in a batch of concrete means corresponding increase in the quantity of cement used.

Approximate Method.—The inspector should not under any circumstances permit an approximate method of measuring to be used, which may yield an excess of sand and broken stone or gravel over cement. If an approximate method is used, same must provide for

not less than the proper proportion of cement, with the possibility that this proportion will overrun. By this is meant that if the barrows of sand and broken stone or gravel are heaping, the proper amount of cement will be used. The usual course of providing a struck barrow of cement and heaping barrows of sand and broken stone or gravel must not be permitted.

Measuring Receptacles.—The measurement of materials may be by bottomless boxes or by headless cement barrels in which the materials may be cast and leveled off; by a properly constructed double gate in a bin chute; by the use of suitable carts or by wheelbarrows having square or cylindrical bodies expressly designed for this purpose; or by automatic measuring devices. If the measurement of materials is determined by weight, the scales should be set at a weight which is a factor of the total weight. Very little time will be required to bring the scales to a balance for each wheelbarrow.

Measuring Cement.—The quantity of cement should invariably be regulated by its weight; if the proportions are stated by volume, a definite weight or number of packages of cement must be assumed to the unit volume as mentioned on page 22. Cement may be measured in the original packages and the packages counted, instead of weighing on scales, since bags or barrels of cement have standard weights. If bags received from the manufacturer contain less than 94 lbs. net of Portland (or natural) cement, the contractor should be required to bring up the weight with additional cement. If the bags weigh uniformly more than is here called for, the contractor should be allowed to remove the excess cement, provided each bag thus altered is altered by weight.

It is important, however, to measure and weigh some sample bags of the cement used on any work, to see that they contain a cubic foot and weigh close to 94 lbs. each. If the bags are found not to contain a full cubic foot, the other proportions or measures for the concrete should be made on the basis of the actual volume of cement in a bag. The inspector should measure and weigh at least one bag in forty as cement is received, in order to check volumes and weights. Every facility must be given to the inspector to properly supervise the process of measuring and weighing. If the cement is turned out of the bags or barrels for the purpose of storing, it should be weighed again as rebagged or packed, and each bag or barrel must contain no less weight of cement than the above unit.

A bag of cement will sometimes contain lumps (see page 29). These should be broken up, or, if they are too refractory, they should be thrown out and good cement used to make up the deficiency.

Measuring Sand, Broken Stone or Gravel.—The sand and broken stone or gravel should be actually measured in bulk. Sand and stone are very commonly measured in wheelbarrows, but this method needs careful watching to maintain uniform conditions. The use of the ordinary shallow round-bottom wheelbarrow should not be considered satisfactory and should not be permitted. The use of barrels or boxes without heads and bottoms, into which the sand and broken

stone or gravel may be cast, the containing vessel then being removed, may be considered satisfactory, or, preferably, the use of square and uniform sized wheelbarrows built specially for this service. Where accurate results are desired, and especially with three or more sizes of aggregate, the use of a bottomless box 8 to 12 in. deep is recommended. No counting of shovelfuls or other approximations should be allowed.

In measuring sand, proper allowances should be made for variations in moisture, and the contractor should be required to make such moisture tests and allowances in measurement as directed.

Measuring in Wheelbarrows.—The most economical measure is the wheelbarrow, and is the ordinary unit of measurement used by workmen for measuring the materials for concrete. A wheelbarrow of *known* capacity is a handy unit of measure.

The measuring of the ingredients of concrete is not very satisfactorily done on the average job. This is because of uncertainty as to the capacity of a wheelbarrow. Where wheelbarrows are used they should be of the straight top type and should be of one size, or the size should be plainly marked if more than one size is used. It should be clearly understood what the volume of the wheelbarrow load shall be called. There is a difference of over a cubic foot between the capacity of a wheelbarrow, water measure, and the heaping load usually carried by workmen in wheeling. An average wheelbarrow contains from 2 to 3½ cu. ft., depending on the amount it is heaped. The measure of the size should be the cubic contents of the barrow "Struck Flat" with a straight edge, no heaping being allowed. This will make the measurement independent of the judgment of the shoveler and will give definite, accurate volumes for each batch.

When measuring sand and aggregate in wheelbarrows, first find out the number of bags of cement a barrow will contain, so as to ascertain the number of barrows of sand and aggregate to use to a given number of bags of cement. In other words, the first step is to ascertain just how much or how many sacks of cement a barrow will hold; then it can be readily figured how many barrow loads of each material are required for a batch of concrete. The wheelbarrows should be checked by means of the standard unit, and the required depth of filling marked. One method of procedure is to make a box just 1 ft. each way, inside dimensions, and fill this twice with the broken stone or gravel and dump it into the wheelbarrow. By observing the amount it is filled, each wheelbarrow load can be heaped or struck off to the same extent. The same is done with the sand, so that the appearance of 2 cu. ft. of sand may also be noted. Then two bags of cement are called one part, or 2 cu. ft., and each wheelbarrow of sand or stone is called one part. For hand mixing a 1:3:6 mixture there would be used 2 bags of cement, 3 wheelbarrows of sand and 6 of broken stone or gravel. Four to six men with shovels would be needed to turn this over (see page 176). A ½-yd. batch mixer could take in the same quantities (see page 167).

This way of measuring in wheelbarrows is not very accurate and not very satisfactory on any but mass work, unless the loading of the wheelbarrows is carefully watched. For ordinary work, however, measuring in wheelbarrows will do, provided the workmen can be trusted or someone is watching them all the time; for the workmen are liable to become careless and not fill all barrows equally if not carefully watched. If there is an incline from the broken stone or gravel and sand piles to the mixture, the workmen are less apt to overload their wheelbarrows, as 2 cu. ft. is about all they will care to push up the grade. The contents for each batch should be carefully mixed in a measuring box until the workmen become accustomed to filling their wheelbarrows in the required manner, and the inspector should require all material to be measured in boxes, if in his judgment the measuring in barrows is not sufficiently accurate.

All wheelbarrows must be brought to a level when filled; a small top on the wheelbarrow load looks like a small matter, but may in fact mean a material decrease in the proportional amount of cement. An unscrupulous contractor also may gradually increase the amount of sand and stone without its being noticeable for some time. Wheelbarrows containing the required amount when level full can easily be obtained. Bottomless boxes made to set in the wheelbarrow can also be used to measure the materials correctly.

Heaping Wheelbarrows (Alternate Clause).—The use of ordinary iron barrows may (with the engineer's consent) be permitted for measuring the broken stone or gravel and sand, provided they are constructed as to contain, when heaped to their utmost capacity, exactly the correct proportions as determined from time to time by the engineer. The barrows should be relatively deep and of uniform size. Their capacities should be determined in cubic feet by actual measurement of the heaped-up contents in a barrow or shallow, bottomless box. The cement being then measured by the bag, the results are likely to be satisfactory, as the most important element (the measurement of cement) is guarded. When such measurement is permitted, no allowance should be made for material which may fall from the barrows in conveying the same to the place of mixing.

Measuring in Barrels.—A more exact method is to use a barrel with both heads out, setting the barrel up on the mixing platform or pile and filling it with the sand and broken stone or gravel, then lifting the barrel, allowing the material to run out on the platform or pile. Set the barrel up and fill it again until each material has been measured. A barrel with the bottom out is a very convenient form of measure for sand and stone, as it is easily filled and more easily dumped. It is not so good as a properly designed barrow or a bottomless box, because more leveling is required after emptying.

Sometimes cement barrels are used to measure the proportions of the ingredients for concrete. This method has the advantage of using the same measuring receptacle for all the ingredients, and also that one or two men can be constantly at work filling barrels with sand and broken stone or gravel, and standing them, handy by, for use as wanted. This makes the work go quicker. As the cement

is shaken down in the barrels it is only fair to the contractor that the sand and stone barrels should be filled heaping. When cement is furnished in bags, bottomless boxes are usually employed instead of barrels. Or wheelbarrows may be used as mentioned above.

Measuring in Bottomless Boxes.—A very satisfactory and accurate method of measuring the sand and broken stone or gravel consists in the use of a box built without top or bottom and provided with four handles at the several corners, made by simply extending two sides and cutting them so that the hand can be easily placed beneath the extension of the sides and the mixing platform. The sides of the box should not be high, from 8 to 12 in. A wheelbarrow could not be dumped over the sides of a high box, and a flat box would not necessitate as much spreading of the materials after the box is lifted as a high box.

For a 1:2:4 mixture in which two bags of cement are to be employed, the sand box may be 2 ft. by 2 ft. by 11½ in., inside measurement, while the broken stone or gravel box should be 2 ft. by 4 ft. by 11½ in. For a 1:3:6 mixture the sand box may be 2 ft. by 3 ft. by 11½ in., and the broken stone or gravel box 3 ft. by 4 ft. by 11½ in. For other combinations the necessary size of box is obvious from these measurements.

Proper measuring boxes specially constructed for the purpose should be provided by the contractor as directed by the engineer. Each of these boxes should, when filled and struck level, contain the prescribed proportions by weight, which should be proved by a reliable scale. That is to say, the boxes should be so arranged as to hold the required amount after "striking" with a straight edge. This will make the measurement independent of the judgment of the shoveler. If other methods of measurement are permitted, the measurements should be based on the measurement of the cement in the original package, and not after being removed therefrom.

Such a box made of the proper size to contain a unit quantity for a batch of concrete can be placed on the mixing platform and filled level full of sand once and of broken stone or gravel twice (or two boxes could be used where the volume of stone is not double that of sand). Using two boxes serves to measure the materials accurately, but it requires more handling to dispose them, after this measuring, in an advantageous position for mixing, thus adding to the expense of mixing the concrete. One method of using the bottomless boxes mentioned above is to measure the sand first in such a box and then spread it over the mixing platform and mix in the cement dry. After this mixing the surface is leveled off and the box placed upon it and filled with the broken stone or gravel. Then the stone is spread over the mixed sand and cement to cover it and the water thrown on and the final mixing done (see page 177).

The bottomless box method of measuring the materials cannot be used in this same way in batch mechanical mixers (see page 171); a dumping square box, however, could be rigged up from which to load wheelbarrows, and exact measurement could be effected in this way.

The bottomless box is not quite so accurate a measure as a properly designed wheelbarrow, that is, a special deep-bodied barrow of one of the types now on the market, because an unscrupulous contractor can more easily heap the materials in the box when the inspector's back is turned.

Automatic Measuring Devices.—To avoid uncertainty and labor in measuring the cement, sand and broken stone or gravel, various automatic devices have been designed, being most used in connection with continuous mixers, but they may be easily adapted to batch mixers if desired. One point to be observed is that all of these automatic devices measure the cement loose, and this must be allowed for in proportioning the mixture, otherwise too lean a concrete will be produced, as mentioned on page 174.

Automatic weighing machines are sometimes used. These usually consist of a series of automatic tipping buckets placed under spouts leading from the storage bins. When the proper weight of material is in the bucket it automatically tips, shuts a valve in the spout, and empties into the hopper leading to the mixing machine. When all three ingredients (cement, sand and stone) have been emptied into the hopper, a valve opens and they are emptied into the mixing machine. When different sizes of stone are used to secure a well-graded aggregate, bins and automatic tipping buckets are supplied for each size.

When automatic measuring devices are used to proportion the concrete, it should be required (1) that they are regulated to give the proper proportions; (2) that the materials do not clog, choke or arch in the feed hoppers; (3) that the feed hoppers are kept amply supplied with materials.

Size of Batches.—Batches should be of such size that they can be proportioned without using fractions of measures. If it is possible, the batch should be of such a size as to take either one or two full barrels, or a certain number of full sacks of cement. This will obviate the necessity of measuring or weighing the cement. In other words, the quantity of concrete mixed at one time should be such as to use either a half-barrel (two sacks of Portland cement) or a barrel (four sacks) of cement at a time. If compelled to use fractions of bags, said fractions should be weighed, upon the assumption that the neat cement weighs not less than 94 lbs. per cubic foot. In this connection, see pages 165, 171 and 178.

Measuring Water.—The contractor should be required to provide suitable means for controlling and accurately measuring water for mixing concrete. Water can be measured by the bucket or by some automatic apparatus. Water should be measured by the pail for small jobs. In this connection, see pages 171, 180 and 193.

Verification of Measures.—The accuracy of the measuring boxes, hoppers, etc., must be verified to make sure that each holds the amount intended. This may be done by using a known measure to fill the measuring box employed, or the volume of the measuring box, etc., may be computed mathematically. Tests should be made by the contractor with the carriers—whether wheelbarrows, boxes or cars—used by him, so that the required proportion of concrete

may be maintained as nearly as possible; and the engineer or the inspector should supervise these tests and fix said proportions for the kind of carrier used at each piece of work. No extra allowance should be made to the contractor for such tests.

Accurate Measuring.—The chief points to be considered in proportioning the ingredients for concrete are to effect the maximum accuracy of measurement with the minimum amount of handling. It is desirable to avoid high lifts of the sand and stone, either in the shovel or in the wheelbarrow. It is also desirable to accomplish these preliminaries to the mixing in the shortest time possible consistent with proper accuracy. The operations of measuring should follow a regular routine or sequence, which should not be varied from, and a double check system should be used by which the cement man and the mixer operator check the number of measures (see page 162). Skipping a measureful when several measurefuls are required to make up a batch is a very common error. Lack of system is mainly responsible for this error.

Accurate measurements are of the greatest importance, and should require (1) that definite measuring units are employed as mentioned on page 150; (2) that the accuracy of the measuring boxes, etc., be verified as stated above; (3) that the filling of the measuring boxes, hoppers, etc., be exact; and (4) that when two or more boxes or hopperfuls, etc., go to make up a batch, the exact number is employed for each and every batch.

Measuring Cement for Reinforced Concrete Work.—No chances which vigilance and caution can avoid should be taken in measuring and charging the cement content of concrete for reinforced concrete work. While skipping a measureful of sand or stone entails no dangerous consequences (a batch of extra rich concrete results simply), it must never be forgotten that a batch of concrete without cement which goes into a girder or column will result in the failure of that member and possibly the failure of the building. The measuring and feeding of the cement should be done under the direction of a superintendent, inspector or foreman having at least two years' experience in handling reinforced concrete. They should by all means be made to understand that safety, life and property depend on the accuracy of their work. The sacks of cement should be counted each day and computation made to see that the proper amount of cement has been used. This should be done in addition to watching the concrete mixture itself (see page 163). The cement sacks are generally tied up in bundles of 100, but too much dependence should not be placed on this and the bundles alone counted. Batches of sacks have been known to run 80 to 90 to the bundle.

ESTIMATING INGREDIENTS

A number of formulas and rules have been devised to regulate the quantity of cement and aggregates to use per cubic yard of concrete, after deciding what proportions of ingredients will be used

(see Art. 13). The best rules governing former practice are given below.

Fuller's Rule for Estimating Ingredients.—A practical rule has been devised by William B. Fuller whereby after the proportions of ingredients have been fixed the quantity of material for a certain work may be obtained. Some years ago Mr. Fuller made a study of the amounts of cement, sand and stone that had been delivered on a number of pieces of work and measured up the concrete made with these materials. From this study he evolved a rule fitted to the barrel containing 3.8 cu. ft., which is called *Fuller's Rule for Quantities,* and is as follows:

Divide 11 by the sum of the parts (by volume) of all the ingredients; the quotient is the number of barrels of Portland cement required per cubic yard of concrete. Multiplying this by the number of parts of sand and of stone will give the number of barrels of each. To reduce barrels to cubic yards, multiply by 0.14 (since a barrel contains 3.8 cu. ft. and there are 27 cu. ft. in a cubic yard). This rule may be expressed in mathematical symbols as follows:

Let c = number of parts of cement in mixture (usually 1).
s = number of parts of sand.
g = number of parts of gravel or broken stone.
C = number of barrels of Portland cement required for 1 cu. yd. of concrete.
S = number of cubic yards of sand required for 1 cu. yd. concrete.
G = number of cubic yards of gravel or stone required for 1 cu. yd. of concrete.

$$\text{Then } C = \frac{11}{c + s + g}$$

$$S = \frac{3.8}{27} \quad Cs$$

$$G = \frac{3.8}{27} \quad Cg.$$

If the broken stone is of uniformly large size, with no smaller stone in it, the voids will be greater than if the stone were graded. Therefore, from 5 to 10 per cent should be added to each value found by the preceding formulas.

Example.—Suppose we wish to mix a concrete in the proportion 1:2:4, what will be (a) the number of barrels of cement, (b) the number of cubic yards of sand, and (c) the number of cubic yards of stone required for 1 cu. yd. of concrete? Then,

$1 + 2 + 4 = 7.$
$11 \div 7 = 1.57$ barrels cement required per cu. yd. of concrete.
$2 \times 1.57 \times 0.14 = 0.44$ cu. yds. sand required per cu. yd. of concrete.
$4 \times 1.57 \times 0.14 = 0.88$ cu. yds. stone required per cu. yd. of concrete.

Fuller's Rule may be modified to fit the bag of cement instead of the barrel as stated above. In such case, the author would suggest the following approximate rule:

Add together the number of parts of each material and divide 40 by the sum. The quotient will be the number of bags of cement required for 1 cu. yd. of concrete. In the shape of a formula the rule appears as follows:

$$b = \frac{40}{c + s + g}$$

in which b = bags of cement per cubic yard of concrete.
c = parts of cement in mixture (usually 1).
s = parts of sand in mixture.
g = parts of stone (or gravel) in mixture.

Take, for example, a 1:2:4 mixture, which means that for 1 cu. ft. (1 bag) of cement (see page 151) there will be used 2 cu. ft. of sand and 4 cu. ft. of broken stone or gravel. Adding, $1 + 2 + 4 = 7$ and $40 / 7 = 5.71$ bags of cement per cubic yard of concrete, or about 1.43 barrels of cement per cubic yard, as against 1.57 given by Fuller's Rule. The sand equals $5.71 \times 2 = 11.42$ cu. ft., or $11.42/27 = 0.42$ cu. yd. of sand, as against 0.44 given by Fuller's Rule. The stone equals $5.71 \times 4 = 22.84$ cu. ft., or $22.84/27 = 0.84$ cu. yd. of stone, as against 0.88 given by Fuller's Rule.

Gillette's Formula.—A very rational and satisfactory formula to govern the proportioning of cement is that devised by Mr. H. P. Gillette. The formula is as follows:

$$N = \frac{27}{p + ns\,(1.1 - 0.9v) + ng\,(1 - 0.9V)}$$

in which
N = number barrels cement required per cu. yd. of concrete.
p = number cu. ft. cement paste per barrel as determined by actual test.
n = number cu. ft. cement per barrel.
s = parts of sand by volume to one part of cement.
g = parts of gravel or broken stone (by volume) to one part cement.
v = percentage of voids in the dry sand, as determined by test.
V = percentage of voids in the gravel or stone, as determined by test.

Figures obtained by using this formula compare very favorably with those obtained in actual test. For the derivation of this formula, see Gillette and Hill's "Concrete Construction, Methods and Cost," page 36, edition 1908.

Art. 15. Mixing Concrete

Concrete mixing is as important as the choice of the aggregates. It is seemingly so simple an operation that it is often neglected by the inspector, and poor workmanship escapes detection. The principal reason for this is the fact that making concrete has been looked upon as simply so much labor, whereas much skill, only to be acquired by experience, is necessary to secure the best results in mixing. Concrete will bear many abuses and still be good stuff, but its strength depends in some degree on proper mixing.

Hand vs. Machine Mixing.—Concrete may be mixed either by hand or by machines, depending upon the volume of concrete to be mixed and the relative cost of the two methods, both of which, if

properly applied, give about the same grade of concrete. However, the work done by hand is likely to be uneven in quality, and some batches will be more thoroughly mixed than others. On the other hand, the work done by a machine is even and regular, and machine-mixed concrete is usually of more uniform quality than that mixed by hand, and is generally less expensive than hand-mixed concrete. The difficulty with hand mixing is to get the work done properly, and should be employed only when the quantity is small or when machinery is unobtainable.

GENERAL REQUIREMENTS

The mixing of the concrete should be done as rapidly as possible. Concrete should not be mixed in larger quantities than is required for immediate use.

Methods of Mixing.—Concrete may be mixed by hand (see page 176) or by machinery (see page 167). The method employed is immaterial, provided the product is a homogeneous mass of the required uniform consistency, containing the proper proportion of cement and aggregate. In either case, however, the methods and manner of mixing should be satisfactory to the engineer and subject at all stages to his approval.

The rules and the practice governing the mixing vary as widely as the proportion of the ingredients (see page 177). Some contractors mix the materials dry till a uniform color and appearance are secured before the water is added. Others put in the material and the water at once. Either way will produce good results except for hand mixing, where the mixing of the materials in the dry state is the general practice. It may be stated, in general, that if too much time is not consumed in the mixing, a good result can be obtained in any of the many ways practiced as described elsewhere, if only the mixing is thorough.

Care or Thoroughness in Mixing.—Whatever may be the proportions chosen, the value of the concrete will materially depend upon the thoroughness of mixing. The kind of mixing required to make superior concrete involves something more than running the ingredients through a mechanical mixer, and something more than shoveling for a given period of time in hand mixing. As the strength of the concrete is very largely dependent upon the thoroughness of mixing, much care is needed in this part of the work. In practice it is frequently cheaper to use more cement or concrete and less labor, but for reinforced work no substitute can be accepted for the most thorough mixing of the ingredients. The contractor should be required to exercise great care with the mixing of concrete and see that it is thoroughly mixed and not allowed to look raw when deposited in the forms.

Too little attention is given by some to the mixing of concrete. It is a matter of primary importance and should be considered accordingly. No matter how suitable for the purpose the materials may be, ***insufficient mixing*** will result in ***inferior concrete.*** Only the other day

the author asked an engineer, who has had a very wide experience, what he considered the most important thing in making good concrete. He said, "Watch your mix." Everybody who knows how little attention is frequently paid to thorough mixing of concrete and with what haste the work is done, will understand that poor concrete is a very common cause of failure. The work is often done automatically; crushed stone, gravel, sand and cement are fed into the mixer in the desired proportions from individual hoppers. Unless the supervision is very severe in such a case, it may happen that one of the hoppers chokes and the material flows less freely, thus entirely changing the proportions of the concrete. Such unintentional mistakes amply suffice to bring about disaster; but if to these intentional carelessness is added and the concrete is weakened willfully hardly anything but failure can be the result.

Thorough mixing is essential in order to produce a coherent and uniform concrete; the leaner and dryer the mixture, the more mixing is required. The mixing must continue until all parts are thoroughly incorporated in the mixture and all stones covered with mortar. The concrete will then be of uniform consistency and color, and if sufficient water only is used there will be no precipitation of the heavier particles in the bin or in the wheelbarrows. If the color of the mass is not absolutely uniform—that is, if uncoated particles of sand or stone are visible; if masses of stones are separated from the mortar; or if some portions of the mortar are drier than others, the mixing has not been thorough. This separation is much more likely to take place if perfectly clean sand is used, especially if the grains are round, and lake or river sand does, therefore, require less water and more care in mixing than bank sand containing a slight amount of clay. *All mixing must continue until the materials are thoroughly mixed.* The analogy with paint mixing is quite pertinent. Most of us know the difference between paint when the dry pigment is simply stirred into the vehicle and when it is ground into the oil. In the case of concrete the aggregate represents the pigment and the vehicle is the most cement. (See page 379.)

Inspector's Supervision.—Concrete should invariably be mixed in the presence of an inspector, and the contractor should be required to notify the engineer in advance when mixing is to be done. Concrete mixed in the absence of the inspector should be subject to rejection at the will of the engineer. Any time the inspector sees any of it slighted he should reject it at once, or have it mixed over.

Inspection of Mixing.—A competent inspector (or foreman) should be in constant attendance to give his approval of every batch of concrete before it is used. The inspector should satisfy himself that the proper proportions of cement, sand, and broken stone or gravel are used, checking from day to day or from time to time with the total amount of each which is received and used. The greatest precaution and vigilance must be exercised continuously so as to be sure beyond any doubt that not *less than the specified amount of cement* goes into each batch of concrete. A check system is absolutely necessary in this matter (see page 158). The inspector

should constantly watch the general appearance of the mixed concrete as it is placed into the wheelbarrows or cars, to see whether the proper proportions have been used. He should immediately investigate any indications tending to show that the proper proportions have not been used. The man in charge of the mixer should also observe the dry batch and see that the cement has not been overlooked.

In these days of machine mixing too little attention is given to the rigorous inspection of the process. On a large piece of work the system used in the mixing of the concrete was such that the sand was thrown in by one man, the broken stone by another and the cement by a third; the latter being called away from his post failed to perform his part, but during the interval the sand and stone went in with rhythmic precision. It is obvious what the effect of these batches of concrete would be and how fatally they would affect the strength of an important part of the structure. In another case the cement, sand and stone were fed automatically from hoppers so adjusted as to give the requisite proportion. At the time of this inspection the cement hopper had choked, but the sand and stone were flowing on and the operator who was totally unaware of the fact, remarked, when his attention was called to it, that he thought the concrete looked rather peculiar.

On a certain piece of work a batch of concrete was made and being deposited when the inspector noticed that it looked "off color." On examination it was found the workmen at the mixer had *"forgot"* to put in the cement. An accident could be the only result if a batch of such concrete should find its way into a beam or column. It must never be forgotten that a batch of concrete without cement which goes into a girder or column will result in the failure of that member and possibly the failure of the building. In massive concrete work a batch without cement will not endanger the stability of the structure, but in column and floor work in buildings it is certain disaster. It is also quite common for a laborer to throw out one-third or more of hard, lumpy cement without compensating for it. This does not make so much difference in mass work, but in thin work it is, of course, vital. Proper inspection (or foremanship) at the mixer is, therefore, highly important, and a cement man who realizes the responsibility of his task is equally important.

Another reason for having an additional inspector on the mixer is that, as a rule, material is more or less superficially inspected by the engineer or inspector by going over the top of a car or barge and digging up a few pockets here and there. Both sand and gravel, however, frequently contain layers of mud near the bottom, which the additional inspector on the mixer would be able to see and condemn.

During the mixing of the concrete the inspector should (1) count the bags of cement (see page 158); (2) see that the measurements are exact (see Art. 14); (3) see that the mixer runs long enough; (4) see that the amount of water is so regulated as to produce the desired consistency or fluidity (see pages 186 and 193); (5) see that

no foreign substances such as wooden blocks, chips, etc., have found their way into the mixture; (6) see that lumps of hard cement are compensated for with good cement (see page 165); (7) see that the proper proportions have been used as mentioned above; (8) see that the concrete is thoroughly mixed—that is, uniform: that it has not balled in the mixer, etc.; (9) see that the mixer is clean before starting (see page 173); (10) see that the materials are running uniform, regular in size, and not mixed with dirt, no single wheelbarrows composed entirely of large stones or of small stones, etc.; and (11) see that proper care is taken in dumping the concrete in place (see Art. 25).

In other words, whether concrete is mixed by hand or by machinery, the inspection should be careful and continuous. The above eleven points should invariably be insisted upon at all times. Particular attention must be directed to the measuring of the materials, their thorough mixing, and the regulating of the amount of water so as to produce the desired consistency.

Engineer's Directions.—The greatest care must be taken to mix thoroughly all concrete so as to obtain the very best results. The engineer's directions must be implicitly followed at all times in this respect, and the engineer should feel at liberty to vary his directions from time to time as the work progresses, so as to insure the accomplishment of this object; and the contractor must forthwith cause such instructions to be obeyed.

"Dry" and "Wet" Concrete.—Concrete should be used "wet" wherever practicable and "dry" only when the nature of the work renders such use unavoidable. The consistency of the concrete should be as required by the engineer. For the consistency of concrete for various structures, see page 187, and for a consideration of the principles to be observed in determining whether to use a wet or a dry concrete, see page 188.

Wetting Stone and Gravel.—The aggregate should be wet before being mixed with the other ingredients, especially in the drier mixtures and in hand-mixed work, and particularly when the aggregate is porous and absorbent. This wetting of the aggregate in the pile allows it time to absorb water that might otherwise be robbed from the cement or the concrete if the aggregate is not wet previous to mixing. In other words, if the aggregate is porous it should be drenched before beginning to mix the concrete, as otherwise the aggregate, by absorbing the water employed in mixing, may rob the cement of the water required in setting, and thus ruin the concrete. This precaution is especially important in hot weather, as the sand and stone must be kept wet in order to reduce the time of initial set to as near the normal as possible (see Art. 32). Obviously, this precaution is also very important with dry mixtures. The aggregate should not be drenched in the vehicles used to deliver it upon the platform or to the mixer, unless proper arrangements are made to drain the receptacles, but should be wetted before they are placed therein. Stone and gravel should contain no loose water in the heap when added to the mortar in the proper proportion. (See p. 348.)

Use of Lumpy Cement.—When used in the work, the cement must be free from lumps and partially set cement. If the cement becomes lumpy before being used it may be thoroughly pulverized before mixing with sand. Hard lumps must be thrown out and replaced by good cement.

It sometimes happens that cement that has been stored for some time, particularly that which has been in the bags at the bottom of high tiers, comes to the job with lumps in it, of varying size. These should be carefully reduced, either by hand or with an apparatus manufactured for that purpose, before the cement is used. Lumps which cannot be broken up with a light blow of the shovel should be picked out, and any cement that has caked so as, in the opinion of the engineer, to be injured, should be rejected and immediately removed from the neighborhood of the site, in order to avoid all possibility of its being used on the work.

Cement containing any appreciable amount of hardened lumps is generally of decidedly inferior quality, and it should never be permitted to enter any important part of a structure. (See Art. 3, page 29.)

Failure to Mix Concrete Properly.—Failure to mix concrete to the required consistency should be sufficient cause for immediate stopping of all work pertaining to the operation in question. Lumps of cement that pass through the mixing process without being broken up render the concrete unfit for use, and the batch should be rejected.

Size of Batch.—The volume of concrete made at one mixing is called a "batch." The size of the batch should be determined mainly by the rapidity with which the concrete can be deposited. Concrete should not be mixed in larger quantities than are required for immediate use (generally one barrel of cement at a time), as the temptation is too great to use it, if mixed, even though the initial set has begun. In other words, it should not be allowed to lie, and then be remixed with water and used. With some cements, concrete used within 1½ hours is all right, but with most, 20 to 30 minutes is about the limit (see page 43). *The size of the batch should not be greater than can be deposited within one-half (½) hour from the time it is mixed.* Two bags of cement with the proper quantity of sand and broken stone or gravel is suitable for a small batch.

Dirt to Be Kept Out of Concrete.—At all stages of the work, concrete and mortar must be kept free from dirt of all kinds, and, if unavoidably mixed with dirt, should be removed and replaced to the satisfaction of the engineer. The inspector should see that no blocks of wood, chips, shavings, lumps of mud or clay, paper from sacks, ice, lumps of hard cement, etc., have found their way into the mixture. *All concrete must be free from dirt or any foreign material.* In this connection, however, don't make the contractor pick out every piece of string, twig or leaf which you happen to see going through the mixer. Use some common sense.

Mixing Coloring Matter.—In using coloring matter with concrete, the color should always be mixed with the cement dry, before any sand or water is added. This mixing must be thorough, so that the

mixture is uniform in color. After this mixing the combination should be treated in the same manner as ordinary cement. (See Art. 42, page 395.)

Amount or Quantity of Water Required.—The concrete, except where required by the engineer to be deposited dry, should be mixed with a quantity of water which will produce a mixture of satisfactory consistency of the wetness required. For the amount of water to be used, and other considerations, see page 193.

Remixing.—When the concrete has to be transported a long distance in cars, and the water has separated from the solid matter, the concrete should be remixed before being placed in the forms. That is to say, concrete which may become compacted or segregated during transportation should be satisfactorily remixed before being placed in the forms (see page 289).

Retempering.—The retempering of concrete which has begun to set before placing is a point over which there is much difference of opinion. The author is of the opinion that as a general rule concrete cannot be retempered properly except in small quantities for laboratory tests. Retempering—i. e., remixing with water—makes the concrete slower setting and reduces the strength of adhesion, this reduction being as much as 50 per cent. The author has observed that in some cases Portland cement concrete appeared to suffer little loss of strength by standing two hours after mixing and then retempering.

If the cement of the concrete has attained its initial set—that is, if the concrete has commenced to harden—remixing with water, or retempering of concrete, as it is called, should not, as a general rule, be allowed; and if concrete treated in this manner has been deposited in the forms, it should be taken out and removed from the site of the operation. In other words, mortar, grout or concrete which has been allowed to stand until initial set has taken place, should not be used, unless by special permission of the engineer, who may, at his discretion, require additional cement to be used in retempering. Some engineers permit the retempering of concrete for mass work where the set is not so hard as to require a pick, provided the practice is not habitual. In this connection, see page 289.

Failure to Place Concrete before Setting.—No concrete should be used after it has begun to set (unless retempering is allowed by the engineer as stated above); when setting commences, the material thus injured should be immediately wasted. If in the opinion of the engineer the contractor fails to take due precaution against such injury, he should charge to the contractor and deduct from the estimate the value of the cement in the material.

Freezing Weather.—Concrete should not be mixed at a freezing temperature unless special precautions are taken to avoid the use of materials containing frost (see Art. 33). The amount of water should be decreased when weather is cool or freezing.

Wet Weather.—Concrete should not be made when rain is falling on it.

Hot Weather.—In hot weather, the sand and gravel, or broken stone, must be kept wet, in order to reduce the time of initial set

to as near the normal as possible. If necessary, the sand and broken stone or gravel piles should be protected from the sun. (See Art. 32.)

Test for Proper Mixing of Concrete.—To determine the proportions of each ingredient in concrete, take samples from different parts of the batch and place each in a tall glass cylinder or tube; add water until nearly full; shake, and allow the contents to settle. The broken stone or gravel, sand and cement will settle in distinctive layers, the depth of which is proportional to the amount of material present in the sample. In this way it is possible to tell if the materials are equally distributed in the mass of concrete.

Test Cubes of Concrete.—It is well to mold a small cube of concrete from the batch occasionally. These cubes will be useful in gauging the kind of concrete turned out, especially in machine mixing, and by the time required for them to set the hardness of the work may be judged. When concrete is placed in unusual conditions, such a sample placed in the same condition and accessible for inspection furnishes an index to the character of the placed concrete. In this connection, see pages 248 and 303.

MACHINE MIXING

Wherever the amount of work to be done is sufficient to justify it, and for all work exceeding 750 cu. yds. of concrete, approved mixing machines should be used. The manner of mixing varies with the type of machine.

If the work is on a large scale a mixer having a capacity of three-fourths of a cubic yard with a hoisting buck of one cubic yard will turn out 175 cu. yds. per day, which is a good day's work for one gang to accomplish good results.

General Classification of Concrete Mixers.—Concrete mixing machines may be divided into two general classes, (1) the batch mixer and (2) the continuous mixer. It is impossible to separate these two classes very distinctly, because many of the machines are adapted to either continuous or batch mixing.

In the *batch mixer* sufficient materials are proportioned to make a convenient sized "batch" of concrete for the mixer. They are then charged into the machine at once, given a certain amount of mixing, and then discharged at once. The batch of concrete may be mixed either by means of moving paddles or blades, or by the rotation of the receptacle itself, in which are generally placed deflectors to aid in the mixing. Batch mixers take a single charge of materials, which on being discharged receive another charge, and so on. They may be of the tilting or non-tilting types. In *tilting* machines the concrete is discharged by raising one end of the drum and causing the mixture to flow out by gravity. In *non-tilting* mixers, steel deflectors are provided in the drums, which plow and pick up the batch as the drum revolves. The batch is discharged by means of a chute so tilted that one end projects into the mixer, receiving the materials picked up by the deflectors and thus allowing them to run out.

In a *continuous mixer* the raw material is fed continuously into the machine at one end, and the mixed concrete is delivered continuously from the other end, more or less adequate provision being made for maintaining the proper proportions of materials. The continuous mixer usually consists of a central shaft to which are attached arms or paddles, rotating in a long trough. The paddles are set at such an angle that they have an endless screw action, cutting and pushing the materials down toward the lower end of the trough, out of which a continuous stream of concrete flows. The materials are dumped on a platform and, after being properly proportioned, are delivered gradually to the mixer, and if fed uniformly the concrete is discharged continuously by the machine. Continuous mixers give a continuous delivery and require a continuous feed. They are usually fed by shovelfuls.

The *gravity mixer* is a type of continuous mixer into which the material is introduced at the top and is mixed by striking various obstructions or deflectors in its descent (see page 175).

Classification of Batch Mixers.—The following classification of batch mixers is made by Mr. Clarence Coleman: *

(1) Revolving drum or cylinder with horizontal axis, with deflectors, receiving and discharging without stopping; concrete visible.

(2) Revolving drum formed with two cones, with horizontal axis, deflectors, receiving and discharging without stopping; concrete visible.

(3) Revolving circular pan or trough, vertical axis, frame with radial arms, receiving and discharging without stopping; concrete visible.

(4) Horizontal revolving cylinder, mixes by revolving about axis, stops to receive and discharge; concrete visible.

(5) Horizontal trough, semi-cylindrical cross-section, longitudinal shaft carrying blades which mix the material and feed it toward the discharge end, receiving and discharging without stopping; concrete visible.

(6) Cubical box revolving about horizontal axis passing through two diagonally opposite corners, door at one side, stops to receive and discharge; concrete not visible.

(7) Same as above, except with corners through which axis passes cut away, tilts to discharge, receives and discharges without stopping; concrete visible.

Classification of Continuous Mixers.—The following classification of continuous mixers is made by Mr. Clarence Coleman:†

(1) Inclined chute fitted with pins, material slides down by gravity; concrete visible.

(2) Series of funnels placed one above another, containing baffles, concrete falls by gravity; invisible for most part.

(3) Long inclined box of square section, revolving on horizontal axis; concrete practically invisible.

* *Engineering News*, Vol. 50, page 187, August 27, 1903.
† *Engineering News*, Vol. 50, page 188, August 27, 1903.

(4) Like (3), except being cylindrical, with deflectors; concrete practically invisible.

(5) Open trough or closed cylinder, fitted with shaft on which are paddles or blades which mix and feed concrete toward discharge end; concrete visible.

Requirements for Effective Concrete Mixers.—The machine must mix the concrete thoroughly so that all of the aggregates shall be coated with a film of cement, and the mixture shall contain a minimum of cement in excess of that which is actually required to coat the particles. The mixer must transfer the materials from one part of the machine to another so that in whatever order they are introduced the product will be homogeneous.

Care should be exercised in the selection of a mixer. Certain mixers that operate well on wet concrete are ineffectual when a drier concrete is used.

Cement being the costly element of concrete, it is of the greatest importance that no more than the proper amount should be used, and it would be poor practice to attempt to cover the imperfections of a concrete mixer by using an excess of cement.

The mixer should provide for separate dry and wet mixing, the cement, sand and aggregate being first mixed thoroughly while dry, the water being then added in just sufficient quantity to make a mixture of the desired consistency.

If a mixer of the continuous delivery type is used the length of the trough should permit a number of turns equivalent to at least twenty per batch, or should be so arranged that the mass can be held in place until it receives such turning.

The determination of the proper amount of water can be arrived at only through good judgment after visual inspection, as the hygrometric condition of the sand is a variable, as well as many other conditions, as mentioned on page 193. Hence, during the entire process of mixing, the mass of materials should be plainly visible to the person who administers the water. The amount of water should be perfectly under control in mixing and should appear in such quantity as may be desired. The mixer should also provide for the addition of the water in a fine spray.

One reason that accounts for the disrepute into which many machine mixers have been brought is that the water regulation is defective. The amount of water should be automatically regulated in all mixing machines, and it should be out of the control of the so-called "water tender." It is possible with a definite gauge to give a uniform quantity of water for each batch, or if desired, to vary the quantity as required. A float can be arranged to shut off the water automatically or to indicate the level on a gauge.

A machine that will comply with the above conditions with a minimum time factor may be classed as a thorough concrete mixer. A machine that fails in any of the requirements stated, is imperfect in direct proportion to the value of the requirement and the degree of the failure.

Some machines produce good concrete, while others produce bad

concrete. If a poor machine is made to produce good concrete through taking sufficient care in the manipulation, then the credit is due to the manipulation. For instance, a shovel is one of the most perfect mixing machines, but the manipulation required is intense. The best machine for practical work is that which will produce good concrete in large quantities with the least time and manipulation.

Batch vs. Continuous Mixers.—All the types of machines have their advocates. A good result can be obtained by any one of them, provided the mixing is thorough. While good results may be secured by either type. the correct proportions are more readily secured in the batch mixer, and this is generally to be preferred, especially for small plants where supervision is likely to be inadequate. With batch mixers, each batch is certain to contain the exact proportions called for and to receive the right amount of turning. For reinforced concrete it has been conceded that batch mixing is preferable. In other words, continuous mixers should be avoided for reinforced concrete work. Many specifications prohibit the use of continuous mixers. A batch mixer mixes thoroughly all the ingredients of a batch, and it can be kept running continuously if the material is not wanted just at the time it is mixed, whereas a continuous mixer has to be stopped, since it will not continue to mix the same material.

In cases of very heavy construction, such as breakwaters, sea walls, dams, locks, foundations, etc., continuous mixers are used to advantage. Continuous mixing is cheaper and more rapid than batch mixing. There are a number of constant delivery, or continuous, mixers that can be safely used, provided a constant watch is kept on the cement feed. This is the most important and the one that gives the most trouble (see page 174).

Type of Mixer—Approval.—The contractor should notify the engineer of the style of mixer proposed to be used, and the engineer's approval of same should be obtained before mixing is begun. That is to say, the type of mixer to be used must be approved by the owner, or city, or its engineer, who shall also control as to the method of feeding materials to the machine. The mixer should be erected and operated in such a manner that the charging, mixing, discharging and regulation of the material is uniform, efficient and certain. It should feed the ingredients in their proper proportions at all times. If at any time the mixer fails to perform the mixing in a satisfactory manner, it must be repaired or removed and another machine substituted.

Batch Mixer.—A batch mixer in which the materials are charged, mixed and discharged in batch units (see page 168) should be given preference at all times for reinforced concrete work. The machinery should consist in part of a box or receptacle in which a definite volume of water, cement, sand and broken stone or gravel—not exceeding a total of, say, 2 cu. yds. in any one batch—may be placed and there mixed by stirring or revolving for an indefinite length of time. The process of charging the machine and mixing the concrete should be conducted in accordance with instructions of the engineer.

Testing Batch Mixer.—The mixer should be tested, and the batch of concrete of the size that will give the best results should be used.

Charging Batch Mixer.—The ingredients should be placed in the machine in a dry state and in the volumes specified, after which clean water should be added and the mixing continued until the wet mixture is thorough and the mass uniform, every particle of stone or gravel being completely coated with mortar. That is to say, in mixing the ingredients the particles composing a batch should come in such contact with one another as will insure the most perfect and equal distribution of the cement throughout the entire mass. Batch machine mixing being the most satisfactory method of mixing concrete, very little fear need be entertained as to the thoroughness of the mix if the ingredients are all measured for each batch.

The proper measures of ingredients should preferably be emptied into the charging box in the following order: First, sand; second, cement; third, broken stone or gravel; fourth, water, the water being so regulated as to produce a concrete of the desired consistency. However, in a batch mixer it does not make any practical difference as to the order in which the material is entered, except that the water should be last. In other words, it is better to mix the materials in a dry state at first and then gradually add the water in a spray and continue the mixing. Care must be taken to run each batch till it is thoroughly mixed dry before beginning to wet up.

The amount of water to be used should be left to a competent man in charge of the mixer, being largely a matter of judgment, as mentioned on page 193. The quantity of water should be regulated according to the appearance of the concrete after placing. Care should be exercised in adding water to obtain the proper consistency. Even if the materials were all supplied under exactly the same uniform conditions, the same volume of water would not produce from each batch a concrete of uniform consistency, because as the concrete is laid the water works up through from one layer to the next, so that more water may be necessary early in the morning than later in the day. That is to say, the water will rise to the surface through successive layers, so that the first batches in a day's work require the most water. It is desirable, nevertheless, to regulate closely the amount of water per batch, as better results can thus be secured. In other words, the water should at all times be added by measure for each batch, thus securing uniformity in this respect, varying the amount from batch to batch as the condition of the materials and the state of the mass require. Water should not be put into the mixer with a hose, as this invariably results in a lack of uniformity in the fluidity of the mix. Some batches come out of the mixer too wet, others too dry. While every batch will not require the same quantity of water because of differences in weather conditions, wetness of the sand, or surplus water in the last batch of concrete placed, it is possible with a definite gauge, to give a uniform quantity for each batch, or if desired, to vary the quantity of water as required.

The mixer should not be filled very full. The spilling is apt to lose more material and cost more for cleaning than the gain in time.

In charging a cube mixer, the ingredients loose should fill the mixer about half full; with a larger charge, the concrete may not be thoroughly mixed. A thorough system should be employed for insuring beyond doubt that not less than the specified amount of cement goes into each batch (see page 158).

Charging Batch Mixer (Alternate Method).—In mixing, the broken stone or gravel may be placed in the mixer first, thoroughly wet. The cement and sand should then be dropped into the mixer in alternate layers and mixed thoroughly until an amalgamated concrete is obtained in which the broken stone or gravel is suspended in a thick paste of mortar. The author prefers to charge all of the materials dry before any water is added, as mentioned above, in preference to the alternate method just stated. For mixtures in which little water is to be used it may be necessary, in order to get a uniform mixture, to mix the dry ingredients without any water first and then add the water and continue the mixing until this is incorporated in the mass.

Number of Turns and Time Required for Mixing.—The number of turns of the mixer, or the time required to effect an intimate and thorough mixture, will depend somewhat upon the kind of mixer. This can be well judged by the uniformity of the product in color and by inspection to see if the grains of sand and the stones are covered with cement. It does not require many turns of a batch mixer to thoroughly mix concrete. About twenty turns of the mixer will generally be all that is necessary if the mixture is to be a wet one. Dry mixtures require longer mixing (see page 188). No matter what the directions of the makers, no batch of concrete should be given less than twenty turns in the mixer.

The number of turns given the mixer before dumping should be left to a competent man in charge of the mixer. However, the requisite number of turns for batch mixers should be determined by trial mixing of a few batches, and, when once determined, that number should be set as the minimum allowable. The product is improved by longer mixing, and all the time less than the period required for initial set, available between deliveries required at the forms, should be utilized for extra turns to the mixer. Some mark should be placed on the mixer so that the number of turns of the mixer can be counted.

The time required for each operation should also be checked, in order to obtain uniform results. When the time of mixing required to give a thorough mixture is ascertained, this length of time may be allowed for each batch, instead of counting the number of turns of the mixer. The time required is generally from $1\frac{1}{2}$ to 2 minutes. It requires about $2\frac{1}{2}$ to $3\frac{1}{2}$ minutes per batch to put in the materials and take out the concrete, if the handling of materials can be expeditiously done. The longer the mixing is kept up, the better, as experiments show that the strength of concrete is increased by mixing up even to $1\frac{1}{2}$ hours after being wetted.

Discharging Batch Mixer (Uniformity of Product).—The color of each batch should be carefully noted as it comes from the mixer. Uniformity of color should be insisted upon. The concrete leaving the mixer must be uniform in appearance and the mixing process must

be carried on until this condition is obtained. The whole mass should have the color of the cement. The entire batch must be discharged each time.

Checking Operations at the Mixer.—The operations of placing the materials in the mixer should be carefully checked and an inspector should be detailed for this work. Workmen may get careless and make a weak batch of concrete if no one is watching, and this one batch of weak concrete may endanger the whole structure in which it is used (see page 163). If considered advisable, however, an inspector at the mixer can be omitted, because the one at the place of deposit, if at all expert, can instantly detect any alteration in the mixture by its color and texture. Of course it is optional with the engineer as to whether or not he wants or considers it advisable to have an inspector at the mixer. A competent foreman must be at the mixer, as mentioned below.

Discharging with a Drop.—Concrete, in discharging the mixer, should not drop or fall for any considerable distance, as a free fall has a tendency to segregate the broken stone or gravel from the mortar.

Cleaning Mixer Platform.—At least once every twenty minutes the mixer should be stopped and the platform upon which the concrete is being fed should be entirely cleared, so that no concrete shall remain long enough to attain its initial set.

Attendance at the Mixer.—A competent foreman must be in constant attendance at the mixer to give his approval of every batch which leaves the machine. The mixer-man is an important person on the job. He should be responsible for speed in feeding the mixer, speed in removing concrete, for accuracy of measurements, amount of water used, cement used, etc. The laborers placing the materials in the mixer should be selected for their intelligence and ability to understand the directions given them.

Care of Mixers.—Concrete mixers must be kept clean. Before stopping at the noon hour the mixer should be thoroughly washed out, and again at night. In using a cube mixer, care must be taken to keep it clean and to prevent accumulations of particles of mortar in the corners or on projections inside the cube. This can be done by pounding strongly on the outside of the cube with a wooden mallet or maul as each batch is dumped out; the remaining clinging particles of mortar are thus detached before they have time to harden in place.

Bearings should be kept in good condition, and where grease cups are used they should be screwed down once every two hours or as often as necessary.

Use of Continuous Mixers.—Continuous mixers, in which the materials are charged, mixed and discharged in a continuous stream, should be used only under special conditions, and then only on mass work, like retaining walls, foundations, dams, etc., as mentioned on page 170. A continuous mixer in the operation of which the proper proportions of the ingredients depend upon the shovelers should be subject to the special approval of the engineer.

The author is opposed, as a rule, to the use of continuous mixers, unless the materials are measured and fed mechanically with a reliable measuring and feeding device. Without such a device the concrete is lacking in uniformity, both as to proportion and consistency. One outfit, observed some time ago by the author, on street paving, will serve to illustrate the lack of uniformity in feeding. Broken stone was piled on one side of the mixer and the sand on the other. Three men shoveled sand into it while five or six others supplied it with stone and yet another put in cement from time to time. The concrete as dumped on the ground was sometimes wet and sometimes dry. Part of it was thoroughly mixed and part was but slightly mixed. This is doubtless an extreme case, but similar ones are numerous and show lack of reliability of such machines when used without proper appliance for proportioning the mixture. However, the author has found that with a thoroughly trained gang and periodic checking of the number of barrels of cement to a given volume of concrete, fair results were obtained.

It requires more careful inspection in using a continuous mixer than it does with a batch mixer.

Charging Continuous Mixers.—Materials should be fed into the mixer in the proper proportions. They may be measured by shovelfuls or by spreading in layers before shoveling into the mixer (see page 152), or by automatic machinery which feeds the cement and each aggregate in the proper proportions. The continuous paddle mixer with a single shaft and an open end is sometimes used for mixing concrete. In such cases care must be taken that the materials are thrown in near enough the upper end to be thoroughly mixed. The water should be fed near the middle of the machine, so that the materials are first partially mixed dry. If the continuous mixer has an automatic measuring device, it should be kept amply full, and the material must not be allowed to clog in the mixing drum.

If a continuous mixer is used careful watch should be kept of the cement hopper, as the cement is liable to run low, feeding only a portion of the worm, or a large lump of cement may ride on top of the worm and hinder the feed; or the worm may become coated with damp cement which reduces the capacity. If the inspector watches the cement hopper the contractor will tend to the sand and stone hoppers.

Charging Continuous Mixers without Automatic Measuring Devices.—If the mixer is fed by shoveling, it should be done from properly proportioned piles of cement, sand and aggregate, and each shovelful should contain a proper mixture of materials. This may be done by having the dry materials measured in a three-layer pile, first the broken stone or gravel, next the sand, and then the cement, using bottomless boxes, headless barrels, wheelbarrows, etc. (see Art. 14). Then shovel in the dry mixture, shoveling from the bottom of the layer of the aggregate. In this way the dry materials will mix as the cement and sand runs down the face of the pile as it is shoveled in. Shoveling must be done at a uniform rate, as it is essential to good results from a continuous mixer, and the inspector

should watch this operation carefully. The chief fault of continuous mixers is the difficulty of charging them properly. Do not allow the dry materials to be mixed and stand any length of time before being wet and used. The sand generally contains enough moisture to cause the cement to set.

The material may be measured by shovelfuls, instead of measuring and spreading in layers before shoveling as mentioned above. In the latter method care must be taken to feed the cement, sand and stone together, and at a uniform rate, the size of shovels being so arranged that when all the shovelers work together the proper proportions will be introduced. If one man shovels cement, two men shovel sand and four men handle the stone, and the cement man stops to fill his pipe, there is likely to be a poor streak of concrete. It is therefore desirable, in feeding a continuous mixer, to spread the measured quantity of stone on the platform, and on top of this place the measured quantities of sand and cement, as described above. Then if each shoveler gets his shovel blade under the whole mass he will have some of each ingredient.

When the materials are measured and spread in layers before shoveling into the mixer, the machine should preferably be below the measuring platform, and two gangs of men employed, one being on each side of the mixer, so that one batch may be prepared while another is being placed in the mixer. To many readers this would appear as a very simple requirement, yet the author has often observed a single gang measure out the materials on the ground while the mixer stood idle, and then lift them several feet, while the mixed concrete fell to the ground, to be shoveled into wheelbarrows or carts.

Testing Continuous Mixers.—A batch of concrete should be measured out in the desired proportions and run through the machine to see if it feeds correctly. After the concrete comes through, it should be examined to see if it is thoroughly mixed and if too wet or dry. If not mixed right, it should be run through again, or mixed by hand. The inspector should check the run of the mixer with measured wheelbarrows from time to time. If an automatic measuring device is used, check its measurements at intervals to see that the feed has not been changed. The cement feed often becomes clogged and will not measure correctly. Several tests should be made each day to see that the cement delivery is constant.

Gravity Mixers.—If the portable gravity concrete mixer is used, the manufacturer's instructions for its use must be adhered to, unless otherwise directed by the engineer.

One form of portable gravity mixer consists of a steel trough provided with staggered pins and deflecting plates. The trough is supported in an inclined position and has a hopper at its upper end, and may be increased in length from 4 to 10 feet by adding different sections. Water is supplied through spray pipes at the side of the trough. The materials—stones, sand and cement—are spread in layers on the mixing platform, with the stone at the bottom. The materials are then thrown into the hopper; they are mixed as they descend through the pins, and the product is caught in wheelbarrows or carts

at the bottom. There is some doubt as to the thoroughness of the mixing obtained, also as to the even tempering of the mixture with water. There is much rough concrete foundation work, however, where this simple form of mixer might be satisfactory.

Precautions to Be Observed in Machine Mixing.—In mixing concrete by machine the important points to be observed are:

(1) That the directions supplied by the manufacturer are carefully followed.

(2) That the specified proportions of the ingredients are fed into the mixer at all times. The entire amount of cement must be added to the other aggregates before mixing is commenced, and the whole should be mixed dry before the water is added. In machine mixing, all the materials, including the water, are sometimes introduced at once without intermediate mixing, but better results are likely to be secured, even with machine mixers, by first mixing the materials dry.

(3) That the quantity of water is uniform and of proper amount to produce the desired consistency. Machine mixing should be carefully studied until one knows exactly how much water may be used.

(4) That the ingredients are thoroughly incorporated before leaving the mixer. Look out for dirty, soft stone and sand and for lack of uniformity in the product of the mixer.

(5) That the entire contents of the mixer are taken out at each emptying.

(6) When the mixer is stopped it should be flushed with water and no concrete, partially set or otherwise, should be permitted to remain in it.

(7) In feeding a continuous mixer by shovel, see that all of the material is fed at the loading end. It is not uncommon to see at least one of the shovel men feeding his material at the dumping end.

HAND MIXING

When from any cause resort to hand mixing is necessary, this should be done thoroughly and to the satisfaction of the engineer. The mixing should be performed as expeditiously as possible and with the use of a sufficient number of skilled men. The contractor should be allowed to use his own method of mixing, provided it gives the desired results, unless the specifications stipulate a definite method to be followed.

The concrete should be mixed on a timber platform, in order to prevent waste of water and material. It may also be mixed, with the approval of the engineer, on the following pavements: (1) asphalt; (2) brick; (3) macadam; and (4) creosoted wood block. When mixing concrete on any of these pavements the street should be swept clean for a place sufficient to allow for mixing the concrete. Mixing concrete on the ground should not be permitted, otherwise loam or clay may contaminate it. The effect of such contamination is a loss of strength, as the clay adheres to the stone and prevents close contact with the mortar.

Hand Mixing for Reinforced Concrete.—All concrete for reinforced work should be mixed by machine as mentioned previously. Hand mixing must be avoided for reinforced concrete work, if possible. This rule is imperative. If hand mixing is required in an emergency, the inspection should be rigid, in order that the work be done deliberately and carefully. In other words, the inspector must pay the closest possible attention to the mixing to see that it is done carefully and with due deliberation. Hand mixing as done for ordinary mass concrete work will not do for reinforced concrete work and should never be tolerated. To secure good results the mixing must be thorough. All hurry that smacks of haste should be avoided.

Methods of Hand Mixing.—There are a number of ways or methods employed for mixing concrete by hand, and they will nearly all give good results provided enough labor is expended. The number of turns, the order of the various operations, and other details of the different methods vary in practice with the notions of the engineer controlling the work. However, it is the general opinion of concrete experts that the relative arrangement of the layers and the sequence of operations for mixing the materials has little effect upon the strength of the concrete, provided the materials are turned a sufficient number of times to incorporate them thoroughly. A good rule for mixing concrete by hand is to mix it enough and once more for luck. Methods variously employed are outlined as follows:

(1) Broken stone or gravel spread, leveled off, and then thoroughly wetted; cement and sand mixed dry and shoveled onto the wet stone, leveled off, and the mass turned, additional water being added if necessary. This method is described in detail on page 179.

(2) Broken stone or gravel spread, leveled off; cement and sand mixed dry, shoveled on, leveled off, and wet as the mass is turned.

(3) Cement and sand mixed dry, and the broken stone or gravel shoveled on top of it and wet as the mass is turned. This is a modification of the second method, the stone being added last instead of first. The water is applied last in both methods.

(4) Cement and sand mixed with water into a mortar which is shoveled onto the broken stone or gravel and the mass turned with shovels.

(5) Cement and sand mixed with water into a mortar, the broken stone or gravel spread on top of it, and the mass turned with shovels. This is a modification of the fourth method, the stone being added last instead of having the mortar placed on the stone.

(6) Broken stone or gravel, sand, and cement spread in successive layers, mixed slightly, and shoveled into a circle or crater, water poured into the center, and the mass mixed with shovels and hoes. This method is applicable to very small batches of concrete.

Specifications for Hand Mixing.—Specifications should stipulate clearly the method of doing hand mixing and the results to be obtained. Specifications are very likely to be ambiguous concerning the number of turns required and as to what constitutes a turn. The inspector should make his mind clear on these important points and should see that there is a definite understanding between engineer

and contractor. In other words, it should be definitely understood by engineer, contractor and inspector what methods will be accepted as satisfactory. If the specifications do not state just how the hand mixing is to be performed, the inspector can use the first method mentioned above and described in detail on page 179. This method has been found by practical experience to give very good results.

Inspection of Hand Mixing.—In general, the mixing of concrete is a simple operation, but should be carefully watched by an inspector, as it is often neglected, resulting in poor or inferior grade of concrete. The inspector should lay the greatest stress upon (1) exact measurement of the broken stone or gravel; (2) thorough mixture of the cement and sand; (3) thorough mixture of the mass; and (4) proper amount of water to produce the desired consistency. For additional precautions to be observed, see page 163.

Size of Batch in Hand Mixing.—The quantity of concrete in each batch should not be greater than the quantity that, under the conditions, can be mixed and deposited in permanent position in the work before the cement begins to set (see pages 157 and 165). Batches should not exceed 1 cu. yd., and smaller batches are preferable, based upon a multiple of the number of sacks to the barrel. If possible, the batch should require either a full barrel or a certain number of full sacks of cement. This will obviate the necessity of measuring or weighing the cement. For the mixing of concrete materials by hand it is usually easiest to make batches which will contain only two or three bags of cement.

Mixing Platform.—A suitable platform must be provided on which to do the mixing. It may be made by nailing together 7/8-in. by 10-ft. boards of any desired width with 2x4 cleats placed about 2 ft. apart. If the concrete is to be mixed near the point where it is to be deposited, the mixing platform must be made portable. A short piece of rope attached to each corner of the platform, or to the ends of the longitudinal scantlings or cleats, will be found convenient in moving it. The planking should be tight enough to prevent leakage of water carrying cement (see page 204). A sheet-iron platform lightens the labor.

The platform should be of sufficient size to accommodate men and materials for the progressive and rapid mixing of at least two batches of concrete at the same time. Batches should not exceed 1 cu. yd. each. For a 2-bag batch the mixing platform should be about 9x10 ft., while for a 4-bag batch it should be about 10x12 ft.

The mixing platform should be boarded off to prevent the wind blowing the cement away while it is being turned dry and to prevent the water running off and carrying away the cement. In many cases it will be found that a 2-in. or 3-in. strip nailed around the edges of wooden platforms will prevent wasting the materials.

Large mortar boxes are sometimes used for hand-mixed concrete.

Proportioning Materials.—In proportioning the ingredients, it is poor economy to make allowance for insufficient mixing or improper handling of the materials. The additional cement will be much more expensive than the extra time expended by workmen in securing a

homogeneous mass. For methods of proportioning, see Art. 13.

Measuring Ingredients.—All ingredients for concrete must be accurately measured as described in Art. 14. No counting by shovels or other approximation should be allowed. A very convenient way to measure the sand and broken stone or gravel is by means of bottomless boxes (see page 156). These boxes should be of such a size that they will hold the proper proportions of stone or sand to mix a batch of a certain amount. Cement is usually measured by the package; that is, by the barrel or bag (see page 153). They contain a definite amount of cement.

Directions for Mixing Concrete by Hand.—The methods of mixing concrete by hand, as to order of procedure, are almost as numerous as are the individuals who do the work (see page 177); but the following method has been found easy and effective:

A correct proportion of broken stone or gravel should be evenly spread upon the mixing platform, and in no case more than 8 in. deep. In a suitable box or on a platform the correct proportion of sand and cement should be thoroughly mixed dry, fine sand requiring much more work than coarse. The measured quantities of sand and cement must be thoroughly mixed by turning them over while dry, at least twice, so that there will not be different proportions of sand to cement in different parts of the heap. It can generally be told by the uniformity of color and absence of streaky appearance when the mixing of the sand and cement has been properly accomplished. If turning the dry material twice does not bring a uniform color to it, the operation must be repeated.

The broken stone or gravel should then be thoroughly wetted and the mixture of dry sand and cement should be evenly spread over it. Commencing at the corners, the men should, with shovels, turn the mass over away from the center, and, coming back, turn it to the center. The shovels should always be used at right angles to either the side or the end of the board, never diagonally. The shovels should go fully down to the platform and the material be turned completely over. In other words, the shovels should always scrape the mass clean from the board, never cut it at mid-depth. As each shovelful is thrown up, a few cuts into the mass with the shovel almost vertical will not only prevent the stones from rolling down the sides, but will materially aid in the mixing. The mass should now be turned inward or toward the center, spread out in layers again, and the operation repeated. In addition to the thorough wetting of the stones, if, in the judgment of the engineer, it will be necessary, sufficient water should be added to the mass by a rose-head sprinkler to enable the material to become thoroughly incorporated, and the process of mixing should be continued until the surface of each stone is well covered with mortar. The entire mixture should be turned not less than three times. An improvement in quality will result by further turning.

Sand and cement should not be mixed up in advance, because the natural moisture which all sands contain will make the cement set and cake.

Hand Mixing (Alternate Method).—The sand may first be spread in a thin layer on the platform and the cement spread over this as evenly as possible. The sand is then mixed by turning it over with shovels into a new pile of the same general shape and thickness as the old one, giving the shovel a smart twist just before the material leaves it, so as to mix the sand and cement thoroughly. Two or three operations of this nature may be required, the material being shoveled from one side of the platform to the other with each turn. After a sufficient number of operations and spreadings of this nature have been carried out it should produce a mixture homogeneous in appearance and color. The water necessary to mix a thin mortar is then added and the mortar spread again. The broken stone or gravel, which has been previously wet, should then be added to the mortar and the whole turned over and over with shovels, first toward the center and then out from the center toward the sides; or it may be heaped up from the sides and ends to an oval-shaped pile; then the mass is turned outward from the center, spread out into layers again, and the operation repeated until all the particles are coated with cement and the mixture is of uniform consistency.

The coarse aggregate may be added before instead of after adding the water, as just described. In this case the broken stone or gravel is spread evenly over the layer of mixed sand and cement. Pour over the top of the broken stone or gravel about three-fourths of the required amount of water, dashing it over the pile as evenly as possible. Again turn the whole material over in the same manner as with the sand and cement, adding water little by little to the dry spots as the mixing continues. Repeat this operation until the whole mass is uniform in color and moisture.

In large work the concrete can be mixed very rapidly by either method as described; as one batch is being finished another can be got ready, and thus a continuous stream of concrete can be turned out.

A variation of the methods described and much practiced, though not to be commended, is the mixing of all the dry ingredients, then adding the water by sprinkling. That is to say, the broken stone or gravel, sand, and cement are spread in successive layers, mixed slightly, water is then added, and the mixing continued. The author has observed that by mixing all the parts dry first, and then applying water, the cement is worked to the bottom of the heap and often cakes there, and, even if turned up again, it has a tendency to adhere to the sand and avoid the stone. At the same time, however, if exceptional care and skill are used in the manipulation, good concrete can be obtained this way as well as any other, but it requires more work to get satisfactory results.

Water for Mixing.—Water should be moderately sprinkled on the material from a sprinkler nozzle, care being taken not to wash out the cement or to put on at any time an excess of water and to leave the concrete too dry rather than too wet. It is essential, however, to have all parts of the batch equally wet; otherwise, by having some parts wet and some parts dry, the drier part will set before the

wetter, and thus cause stresses within the mass, which sooner or later lead to ugly cracks. A good plan is to tie the nozzle of the hose on a shovel-blade so the blade will spray the water. With a little experience the man with the water will be able to regulate it so that each batch will have about the same amount of water. After the water is added the turning must be continued until the whole mass becomes homogeneous. The water must not be dashed upon the mass by means of a jet. Do not lose any of the water by letting it run off the edges of the platform.

In adding water by means of buckets, care must be taken not to dash it on in such quantities or with such force as to wash the cement from the aggregate. Some engineers specify that the concrete must be wetted by means of buckets, feeling that it can be gauged more accurately by filling the required number of buckets in advance than by spraying with the hose.

The quantity of water is regulated by the appearance of the concrete, as mentioned on page 171. Nearly all the water can be poured on the dry materials before commencing to turn, and the remainder used to wet up occasional spots. (See also page 193.)

Natural Mixture of Sand and Gravel.—When a natural mixture of sand and gravel is used, the material should be handled the same as sand—that is, it should be spread evenly, and, after the addition of cement, mixed dry and then wet.

System in Hand Mixing Operations.—The mixing operations should be conducted according to a regular system. If a gang of men are started properly they will soon become expert, working in unison; whereas, if each man is allowed to mix according to his notion, confusion is sure to result. A regular system permits the inspector to check the work and tends to produce uniformity of product that decreases the necessity of constant inspection for and correction of faults in the mixture.

Care or Thoroughness in Hand Mixing.—Hand mixing cannot be expected to be as uniform as machine mixing, and yet, if proper care is taken, under intelligent supervision good results can be secured. Mixing must be done on a clean platform or on a clean pavement. Special care must be taken to prevent the incorporation of any dirt or foreign matter into the concrete. In fact, during the whole process of making concrete it is absolutely essential to avoid admixture with earth, clay, dirt, sawdust, chips, or other undesirable material. Care should also be taken to keep the sand and broken stone or gravel in distinct and separate bins or piles. That is to say, the shovelers should always maintain a clear space between piles. The mixing must be conducted in a manner which will not permit of the loss of cement through the running off of surplus water.

In hand-mixed concrete, the ingredients should be very thoroughly mixed: too much importance cannot be placed upon this feature of the work. Mixing concrete properly is hard work, and also requires some skill, but it is of the utmost importance that it be done thoroughly. Thorough mixing will produce a more plastic concrete with a given amount of water than inadequate mixing. The material

must be turned over thoroughly, the shovels must find their way to the boards, and the mixture must be picked up from the bottom and turned over and over again. The shoveling of concrete is hard work, and it will be found necessary not only to pick good men for this duty but to cull them until the evolution results in the proper men for the work. A thorough *turning over* must be demanded by the inspector, not a mere haphazard shoveling. This is far from being easy work, and, especially in warm weather, the men are inclined to become optimistic and to believe that a batch of concrete is finished when in reality it is only about half mixed.

A few wheelbarrows of badly mixed concrete sent back to the mixing platform for better treatment will have a more lasting effect on the concrete gangs than a lot of talking to them.

Number of Turns.—Specifications for hand mixing should always state the method to be followed (see page 177), and particularly *the number of turns necessary.* If these matters are not specific, the contractor has to guess at the probable requirements of the engineer. Specifications are very often ambiguous concerning the number of turns required and as to what constitutes a turn. The inspector should make his mind clear on these points and should see that there is a definite understanding between engineer and contractor. The author has known of inspectors demanding from 5 to 10 turns of the materials when specifications were ambiguous. It should invariably be made clear whether or not the final shoveling into the wheelbarrows or carts constitutes a turn, and whether any subsequent shoveling of the concrete into place constitutes a turn. Inspectors and foremen have frequent disputes over these questions.

While the specifications should state the greatest number of turns, the inspector should be allowed to require a less number in special cases; for when the materials are thoroughly mixed it is time to stop, and any further manipulation will rather tend to separate, and not mix the ingredients. Again, an experienced gang will make a better mixture by turning the materials over three times than a green gang will make in ten turns.

The number of times concrete should be turned over will depend upon the method of handling it, the nature of the sand and broken stone or gravel, also the amount of water added. Merely shoveling the material from one part of the platform to another should not be considered a proper method of mixing. The contractor should be required to turn the sand and cement at least three times dry and three times wet, and then turn the mortar and stone three times. Material turned less than three times after it has been wet cannot be considered as well mixed. The whole mass must be turned over with shovels at least three times (not counting the shoveling off the board), or until thoroughly incorporated. With experienced laborers, the concrete should be mixed after three such turnings; but if it shows streaky or dry spots, it should be turned again. The engineer may prescribe the number of times the mixture shall be turned, dry and wet, if he considers it necessary. Some specifications have required six turns dry and three turns wet for the mortar, followed

by three turns of the mortar and stone. In pavement foundation work two turns of the mortar followed by two turns of the mortar and stone are sometimes permitted, but the author feels that this is rather insufficient even for concrete in such work.

Order of Turning Materials.—The order of turning should be so regulated that the last turn made will place the material in a single pile at or near the center of the board, preparatory to its removal to the place for it in the work.

Removal of Concrete from Platform.—In removing the concrete from the platform, care must be taken to preserve the incorporation, which can best be done by shoveling it from the base at the edges of the pile toward the center of it, and at the same time cutting the apex of the pile with a hoe or shovel, in such a manner as to avoid an accumulation of loose stones.

Cleaning Platform.—When the day's work is done the mixing platform should be left clean, and if any mortar or concrete is not used it should be removed, to prevent it from being remixed again in the morning. The platform should be scrubbed with a broom and water. If this is not done, small particles of stone will be glued to the platform by the cement and will render shoveling the next day most difficult.

Tools for Hand Mixing.—In mixing by hand the men should be provided with long-handled, square-bladed shovels, as they can reach the center of the pile better and will not tire themselves as with a short-handled shovel. The use of a rake or a hoe may be permitted in mixing sand and cement, but preferably not after stone has been added. Shovels for mixing concrete should be square-pointed rather than round, with proper shape of bowl and a definite length of handle, to enable the user to turn the mass quickly and with the minimum amount of labor. Some contractors prefer hoes, and others use rakes, claiming for the latter the advantage of separating the material in a manner impossible with shovels, except in a long throw. An expert with a hoe can give to the mortar a motion that not only turns it over but separates and spreads the particles as well. Square-pointed shovels, size No. 3, are used the most for mixing concrete by hand.

Mixture of Mortar Having an Excess of Water.—Any mixture of mortar having an excess of water (of which the engineer or the inspector should be the judge) should be rejected, and must be removed from the platform and evenly spread on top of the finished concrete, where and as directed; or if, in the judgment of the inspector, it may be used in the concrete, in such case it should be his duty to see that at least two or three measures of broken stone or gravel are omitted from the batch.

Removal of Mortar from Platform.—If any mortar is removed from the platform for any purpose, it should be the inspector's duty to see that at least one or more measures of broken stone or gravel are omitted from the batch. Mortar required for other purposes should be prepared separately, as each batch of concrete must have its full proportion of cement.

Protection against Wind and Rain.—In mixing concrete by hand, the operation should be well protected against wind and rain, as the rain prevents proper dry-mixing of sand and cement, and the wind tends to blow away the fine cement, which is the best material. (See page 333.)

CONCRETE MIXING PLANTS

With the actual handling of materials for concrete the inspector has little to do, his duties being restricted to seeing that the quality of the work is maintained rather than the means used by the contractor to carry on the work. However, as the inspector is interested in the progress of the work to see that it is completed in the time agreed upon, the method of handling the materials for concrete may become of vital importance. The author will therefore discuss the subject very briefly.

It is not to be assumed that any one hard and fast rule can be applied to the economical handling and arrangement of the mixing plant and here is where the contractor's ingenuity and natural resource must come into play. All conditions, local and otherwise, must be taken strictly into account and harmonized one with the other. One thing that will work well in one place will not do at all in another. The one item to be constantly kept in mind, with a view to eliminate it as much as possible, is that of rehandling the materials.

Besides handling concrete, the plant, as a rule, has to do the following work (difficult foundation not considered): Excavate, sheet pile, mix and transport mortar, mix and transport concrete, handle lumber for falsework and forms (including demolition), handle steel, coal, broken rock and back fill. Several of these items should be carried out at one time to execute the work economically, which gives preference, as a rule, to derricks rather than cableways.

Capacity and Arrangement of Plant.—The concrete mixing plant should be consistent with the size of the work and efficient for the purpose. The capacity of the mixing plant is determined by the amount of concrete to be placed and the time available for placing it. Its division and arrangement are determined by the size of the work and the type and arrangement of the plant for transporting the materials and the mixed concrete. In other words, the arrangement of any concrete plant must be determined by local conditions, such as the contour of the ground, the distance from which the raw materials are transported, and the class of construction. Concrete mixers seldom have enough power behind them to produce their rated capacity. To get concrete to and from the mixer is more difficult than to mix the concrete.

Everything should be arranged in such a manner that the materials will find their way automatically, as it were, from the unloading teams or cars and into place in the forms with the minimum amount of hand labor, all things being consistently worked out with the layout of the grounds and the structure in prospect.

If the reader is interested in the design or in the arrangement of plants for handling the raw materials and the concrete, he can

obtain a description of many plants, successful and economical in operation, from almost any of the standard books now published on the subject of Concrete or Reinforced Concrete, and in the volumes of *Engineering and Contracting, Engineering News,* and *Engineering Record.*

The following general principles may be laid down:

Location of Materials.—The sand, broken stone or gravel and cement must be located where they can be dumped from wagons and with one handling delivered to the mixer or the mixing platform.

Location of Mixer.—The mixing should be done as near the place where the concrete is to be deposited as possible, so as to avoid having to carry it a long distance. It should also be done as near as possible to the place where the ingredients are stored. In building work the mixing should be done at a point on the ground which is directly under the forms being concreted. Of course, it is impracticable to secure so direct a route as this from mixer to forms, but it can be more or less closely approached, using two mixers, for example, one at the front and one at the rear of a building, cutting down the haul from hoist to forms one-half. In other words, the mixing should be done as near the place of concreting as practicable.

Care must be taken to see that wheelbarrows, dump-carts, or whatever conveyances for the materials are used have easy access to the mixer or to the mixing box.

Gravity Handling of Materials.—The most possible use of gravity should be made. It is frequently economy to carry all materials to the tops of bins, from which points they can move by gravity down through the mixer to the hoist buckets. That is to say, the materials should be stored high where possible. If raised to bins, when delivered on the job they may be drawn out with use of little labor. This storing of the materials may often be done by the use of cranes or by inclined chutes. It is better to handle the materials in this way than to dump them on the ground and shovel them up. They will be cleaner, and the stone is less likely to run irregular.

If possible, the mixing should be done at a higher level than that at which the concrete is to be placed, to avoid lifting materials, as it is easier and cheaper to lower materials than to raise them; in fact, the concrete may sometimes be slid to place down a trough or chute (see Art. 35), or the mixer so placed that the materials move continually down hill. In other words, where natural elevations or basement floors below street level, etc., permit gravity handling, they should be taken advantage of in every instance.

One method of raising materials to the mixer is to use an incline with a gravity dumping-car to material pile. This is drawn up to the mixer by cable from the mixer engine or other power, and allowed to return by its own weight.

Care of Machinery.—The best results can be obtained with all parts of machinery and boilers put in good condition before starting the work and kept in good repair throughout the period—don't wait for breakdowns before repairing.

CONSISTENCY OF CONCRETE

Terms for Specifying Consistency of Concrete.—The terms for specifying the consistency, or degree of wetness, of freshly mixed concrete are variously used by different engineers, but the following terms are very commonly used to designate the consistency or degree of plasticity of concrete, i. e., *dry, medium,* and *wet.* Occasionally the terms dry, wet, and very wet are used.

A *dry mixture* may be described as having the consistency of damp or moist earth. It will retain its shape when squeezed in the hand. It is mealy in consistency, with no visible superabundance of moisture, just enough water being used to satisfy the needs of the cement in setting; that is, only sufficient water to cause the necessary chemical action required for the setting of the cement. Moisture will just flush to the surface under prolonged and vigorous ramming, and then simply in a glistening film.

A *medium* or *quaking mixture* means a soft, tenacious, jelly-like consistency, which shakes or quakes like liver or jelly on ramming. Water flushes easily to the surface. Such a mixture does not quake in handling, nor under light tamping, but must be well or heavily tamped.

A *wet* or *mushy mixture* is one which cannot be tamped and into which a man sinks to his ankles or above in walking over it—so thin as to flow easily. It has the consistency of very soft mortar and is so nearly liquid that it cannot readily be shoveled, but is poured into forms; that is, it will run off a shovel unless shoveled very quickly. It will spread out and settle to a level surface after wheeling about 25 feet in a wheelbarrow. Wet concrete will quake in handling, and into it an ordinary rammer will sink of its own weight. This mixture is sometimes called "soupy" concrete (see page 195).

The Proper Consistency, or Wetness, of Concrete.—There is considerable diversity of opinion among engineers as to the amount of water to be used in making concrete, some still holding to the very dry mixture, while others prefer one nearly as liquid as grout. At present only comparatively few advocate the use of dry concrete, and most engineers prefer a plastic or quaking mixture; but a considerable number use a wet or mushy concrete. Thus it will be seen that the proper consistency, or wetness, of concrete is a disputed point among engineers, but in recent years there has been a decided tendency toward the use of more water than formerly. In fact, there has been a marked tendency in the past seven years (1906-13) to the use of wet or "mushy" concrete, and few engineers now prefer dry mixtures, while the medium or quaking is gradually giving way to wet mixtures. In general, a wet mixture is desirable, in order to make concrete with a minimum of voids. Few concrete experts approve of dry concrete, although it possesses a few advantages in mass or heavy work, as mentioned on page 188.

Formerly, when mass concrete was about all the kind made, very dry concrete was generally specified. The cement, sand and broken stone or gravel were dampened to such an extent that a handful,

when squeezed, would retain its shape, but the hand would not be wet or stained and the lump would fall to pieces when shaken. It was like moist brown sugar or damp earth. When "dry" concrete was deposited in forms it was required that it be tamped or rammed until the moisture rose to the surface and the concrete quaked. It was really remarkable to see how little water was required to make a mushy-looking concrete after considerable ramming, but the manipulation becomes so difficult with dry concrete that quaking concrete soon became commonly or almost universally used, and at present there is a tendency to exaggerate the amount of water. In other words, the tendency in all kinds of concrete construction is to use a wetter mixture than formerly.

Concrete should be mixed as wet as possible without having any free water to wash the cement off the stone. The usual practice is to make the consistency such that the concrete will require only moderate tamping or puddling to bring the mass to a homogeneous condition. Any man who advocates using concrete drier than this has not kept up with the advances of engineering knowledge in the last few years. If, however, the engineer requires dry concrete, the inspector should see that he gets it.

Consistency of Concrete for Various Structures.—The proper degree of wetness depends upon the purpose for which the concrete is to be used. The following is presented as a general guide:

Dry concrete may be used in dry locations for mass foundations which must withstand severe compressive strain within a few weeks after placing (see page 192). Dry concrete should be spread in layers not over 6 in. thick, and thoroughly rammed (see page 296).

Medium or *quaking concrete* may be used for ordinary mass concrete, such as foundations, retaining walls, large arches, abutments and piers.

Wet or *mushy concrete* should invariably be used for rubble concrete (see Art. 34) and for reinforced concrete, such as thin building walls, columns, floors, conduits, and tanks.

Consistency of Reinforced Concrete.—Concrete should be mixed wet when applied to metal reinforcement, being so mixed that it must be handled quickly or it will run off the shovel, or so that it will assume a level surface when dumped into a wheelbarrow and wheeled about 25 ft. The consistency of the concrete should be soft and wet, without being sloppy, and in general should be such that after dumping the concrete in the forms it may be consolidated and worked into place by means of puddling or light tamping, as described on page 296. It is essential that the concrete should be sufficiently wet to pass between the reinforcing bars, particularly in such portions of the work as may contain a large amount of reinforcing bars, or the like, placed closely together, and to thoroughly surround every portion of the steel. This should be insured even at the expense of having the concrete wetter than otherwise desirable. Care must be taken, however, that the concrete is not *too* wet, so that the stone and sand settle under the water during its transportation to the forms or after being placed in the forms.

In other words, the materials should be mixed wet enough to produce a concrete of such a consistency as will flow into the forms and about the metal reinforcement, and which, on the other hand, can be conveyed from the mixer to the forms without separation of the coarse aggregate from the mortar. A good concrete worker can tell whether the concrete allows of easy tamping and runs freely around the steel bars. Where the reinforcement is not very closely spaced it is unnecessary for the concrete to be so wet. However, what is usually known as a wet mixture should generally be used for reinforced work. In other words, the mixture should be moderately wet, and no very wet nor very dry concrete should be used without special permission from the engineer in charge.

Concrete must never be mixed too wet and the cement drowned out. The tendency of the contractor is to make it much too wet, the cement then being washed to the lowest point of the forms, and the rest of the concrete suffering in consequence (see page 195). Mixed too wet, concrete never attains its full strength. The mixture must not be so thin that it will seep through the joints in the forms.

WET VS. DRY CONCRETE

A consideration of the following principles will be useful in determining whether to use a wet or a dry concrete:

Quick Set and Early Strength.—Dry mixtures set more quickly and gain strength more rapidly than wet ones; therefore, if a piece of construction is to receive its load soon after placing the concrete, it is best to use a dry mixture, if the conditions are not such as to render such a mixture harmful for other reasons. In other words, the drier concrete will attain its strength sooner than wet concrete, and if quick set and early strength are desired, dry concrete should be preferred. Forms may also be removed sooner with dry mixtures. *For quick strength use as little water as will make good concrete.*

Mixing.—Lean concretes should be mixed rather dry, since if quite wet the cement will find its way to the bottom of the layer and destroy the uniformity of the mixture. Lean mixtures require more mixing than rich ones, because it is more difficult to distribute the smaller amount of cement through the mass. Dry mixtures require more mixing than wet ones; and therefore if the concrete is mixed by hand and the supervision is insufficient or the labor is careless, or if the machine by which it is mixed is insufficient, wet mixtures are to be preferred. However, the liquid state of the concrete may make an insufficient amount of mixing appear to be enough; so that practically as much vigilance is required to insure the proper mixing.

In mixing concrete there is a tendency for the cement to ball up, or form nodules of neat cement; while in mixing wet this does not occur. It is not uncommon in dry work to find in the interior of walls, when torn down, lumps of unset materials which had been rolled up into balls coated on the outside with cement, these balls having been formed during the mixing process. When a large amount of water is used such balls cannot form. Dry mixtures are much

more liable than wet ones to ball even in mixing machines—that is, to gather in lumps, as the materials will not flow well without the lubricating water. With no water whatever in the mixer there would be no cohesion and the material would mix, whereas a little water would give a cohesion that may result in the balling referred to above. It may be necessary in some cases to mix the materials dry and then add the water, giving the mixer a few more turns (see page 171). While hand mixing in general is less satisfactory than machine mixing, it is possible that in some cases for very dry mixtures hand mixing will produce better concrete.

Handling and Placing.—The inconsistency of the mixture will often govern the methods of handling and depositing. With a dry mixture there is a tendency for some of the stone to separate from the mortar on the slightest provocation. Great care is necessary in hadling and placing dry concrete to secure a uniform mixture throughout the structure. One of the arguments against very dry mixtures is the difficulty of obtaining a uniform consistency. Occasional batches will invariably be too dry, and it is impossible, with ordinary care in placing and ramming, to avoid visible voids or stone pockets which form weak places and allow the penetration of water. (See page 348.)

With a wet mixture there is less tendency for the materials to separate. In the days when dry concrete was common it was believed that an excess of water caused the materials to separate and the cement to settle to the bottom. Thousands of tests have demonstrated that there is no tendency on the part of the cement to settle to the bottom and separate from the aggregate and sand if the concrete is of the proper consistency. Mixtures too wet, however, will separate and the cement will go to the bottom, or the mortar will run away from the stones. This may appear an imaginary danger to many users of concrete who have never employed a very wet consistency, but the author has seen concrete mixed with too much water, which after setting and the removal of the forms had the appearance of being mixed too dry. This applies to very wet concrete, which contains so much water that with ordinary care in hand mixing it cannot be made to incorporate with the other materials.

In thin walls very wet concrete can be more easily "joggled" into position than dry concrete, and will give a smoother surface.

Ramming or Tamping.—Wet mixtures can be compacted into place with less effort than dry. Dry concrete requires ramming or tamping, otherwise it will be weak and porous; the drier the concrete, generally the heavier the tamping necessary. Therefore, if the concrete cannot be rammed it should be mixed wet and then the stones by their own weight will bury themselves in the mortar and the mortar will flow into the voids. Dry concrete for this further reason is unsuitable in reinforced concrete work. Tamping around reinforcing steel is very likely to displace the steel as well as to disturb or spring the forms. The concrete around the reinforcement should be worked into the spaces by puddling rather than by tamping or ramming, and the consistency of the mixture should be such as to admit of this operation (see page 190). When concrete has to be thoroughly

tamped, it is hard to figure on the strength of forms, and bulging forms may be common. With wet concrete the pressure is always uniform and can be calculated and the forms designed accordingly.

A rich concrete can be compacted much easier than a lean one, and hence rich concretes can be mixed drier than lean ones. The quaking of concrete is due more to the excess of mortar than the excess of water.

Gravel concrete can be more easily compacted than broken stone, and hence may be mixed drier.

Water-Tightness of Forms.—With concrete too wet, unless the forms are very close, approximating water-tightness, liquid mortar will be wasted through the cracks or joints. This is a fault sometimes met with in concrete work, namely, the mortar being of too watery a consistency, or the forms lacking the proper tightness, not only results in a waste of mortar but mars the appearance of the finished work by leaving the concrete spongy or with holes where the mortar has leaked out. In other words, if wet concrete is deposited in wooden forms, there is liability of the water escaping between the joints and carrying away part of the cement and thus weakening the face, which should be the strongest part of the mass. This may give the appearance of dry concrete, whereas the cause is just the opposite. Dry mixtures are of advantage because the forms need not be as tight, but more mixing of the dry materials and more tamping are required as stated above. *Where a wet concrete is used the forms should be nearly water-tight.*

Reinforced Concrete.—When the concrete is reinforced, dry concrete cannot be used, for it is absolutely essential that there be no displacement of the steel or disturbance of the bond between the steel and concrete. If dry concrete with the necessary ramming or tamping is used, the steel will generally be moved a little and the bond between the steel and the slowly-setting concrete will be disturbed. Dry concrete is also unfit for reinforced work, as it will not flow around the steel and coat in with cement. Because dry concrete is porous, there will be voids around the reinforcement as well as in the other parts. The steel is thus deprived of the protection which the concrete must afford if the combination is to be lasting.

For reinforced concrete work there must be found a mean between too wet a concrete and too dry a concrete that will meet the conditions. The proper mean is not a mixture medium in consistency, but a very wet mixture. It should flow readily around the reinforcing steel, and require little or no tamping, and at the same time pack around the steel, covering it with cement. Both of these requisites are of prime importance in reinforced concrete. The reinforcement will not be gripped as firmly in a porous concrete as in a dense concrete. Wet concrete shrinks more than dry concrete on setting and drying, and is an aid rather than a detriment in reinforced concrete, because it would grip the steel. Dry concrete lacks cohesion, and the cohesion of concrete has much to do with the gripping of the steel. *Wet concrete, which flows readily around the steel, is the only*

concrete to use with reinforcement. Other works than reinforced concrete do not generally require such wet mixtures.

Rubble Concrete.—A dry mixture is unfit for use in rubble concrete or concrete rubble, because it will not flow around the large stones and coat them with cement. A very wet mixture is more suitable for cyclopean or rubble concrete, because the large stones more readily settle into place and bed themselves.

Water-Tightness.—Dry or mealy concrete is unfit to use in walls that are to keep out moisture, as it cannot be rammed to a very dense mass. A mealy concrete wall allows water to flow through it very freely. Work that is to be waterproof or nearly so should be made of a wet mixture (see Art. 47) and should be puddled, as in the case of reinforced concrete, to work out air bubbles and to solidify the mass. *When it is desired to make concrete waterproof it should be mixed wet.* A great excess of water must be avoided, as it not only makes the concrete porous, and therefore weak, but also tends to destroy the cement by the washing out of the finest particles.

Shrinkage Cracks.—If concrete is mixed too wet it will shrink an excessive amount on setting and drying. This may give rise to shrinkage cracks or other trouble that such change of volume would naturally lead to.

Formation of Laitance.—If the concrete is mixed with a great excess of water (sloppy concrete, for example), when it is deposited in place the excess of water will rise to the surface and carry with it the finest or active particles of cement, which will decrease the strength of the concrete and also deposit upon the surface of the mass a light-colored powdery or slimy substance, called laitance (see Art. 31). This substance is composed of about the same ingredients as the cement, but it does not harden as the cement, remaining rather in a gelatinous state. Besides taking from the cement useful elements needed in the concrete, the laitance, if not removed, will prevent the adhesion of the next layer of concrete by leaving a film in the concrete where it is not bonded together as it should.

Curing.—Dry mixtures require more wetting subsequent to placing than wet mixtures, because to set properly requires a certain amount of water. If this is not all supplied in the mixing, it should be supplied afterward. In other words, concrete requires water in order to set and harden properly, so the necessary water must be supplied later if it is not supplied during the mixing period (see Art. 29).

Strength.—As to the strength attained by wet and dry mixtures, tests have been made which show that the dry concrete becomes much stronger in a short period of time. That is to say, it is found that, given a number of samples of different consistency, the drier mixtures will at first show greater strength. In other words, dry concrete obtains a certain degree of strength in a shorter time than it takes wet concrete to obtain the same strength. After a few days the mixtures having more water will attain the strength of the drier

ones and begin to surpass them. Wet concrete and dry concrete placed in the same day are of practically equal strength at the end of 30 days, but at the end of the first five or six days the dry concrete is the stronger. After 30 days the wet-mixed concrete gains rapidly in strength as compared with the dry-mixed concrete, the latter picking up in strength if wet with a hose or otherwise drenched with water. Three months after mixing the wet concrete is much stronger than the dry concrete, and it always retains this advantage, but as the years go by and the dry concrete has an opportunity to absorb moisture and the wet concrete gradually loses excess moisture, the difference becomes comparatively small.

In general, the more water used in the mixture, the longer it will be in attaining its full strength. Medium and wet mixtures, after many months, reach about the same strength. Very wet and very dry mixtures are both weaker on long-time tests than those in which the consistency is not excessive.

Dry concrete is not stronger than wet concrete. Thousands of experiments have conclusively proven this idea to be wrong. *The wet mixture if allowed to harden for a long period will ultimately become stronger than the dry mixture.*

Conclusions.—The conclusion is that dry concrete must be employed where great strength is required at an early date; but it must be thoroughly rammed or tamped—a thing difficult to secure with ordinary laborers. Dry concrete is advantageous for the first layers in wet excavations. The drier the concrete, the closer the inspection required when the material is placed, there being a tendency for some of the stone to separate from the mortar on the slightest provocation. Experiments show that dry mixtures attain their strength more quickly than wet mixtures, but that medium mixtures produce a denser and stronger concrete, and, except for reinforced concrete, are to be preferred to wet or dry mixtures. In other words, plastic or quaking concrete is suitable for plain concrete in large masses, but care is required to secure a solid surface.

Wet concrete is more economically placed than dry concrete, for it is mixed in a shorter time and requires little or no tamping. It settles readily into all corners and crevices, and thus presents a finer appearance on the surface. The wetter the concrete is, the easier it will be put in place. Better appearing work can always be done with a flowing concrete, and will usually give a solid surface next to the form without any special care. A wet or mushy mixture must be used for reinforced concrete. For permanent strength and low cost in mixing and depositing, use wet concrete. Wet concrete is much more uniform in strength than dry concrete, and plenty of water is required to harden concrete.

Concrete should not be too wet or too dry. If too wet, it will shrink an excessive amount in setting and hardening; if too dry when placed, it will not be dense, as the mortar will not run into the spaces. It is better to use too much than too little water, but mixtures that are too wet are not so strong as medium mixtures, and must be promptly poured to prevent segregation of the materials.

In fact, mushy or fluid concrete is considerably weaker than dry concrete, and requires tighter forms, but does not require any tamping. *For general use, concrete mixed wet is better than a dry mixture, although the amount of water which should be used is not the same in all cases.*

QUANTITY OF WATER REQUIRED

No hard and fast rule can be laid down to gauge the proportion of water required for concrete. The amount of water required to produce any particular plasticity or consistency varies so greatly with the proportions of the ingredients; the kind and fineness of cement; the character, porosity and dampness of the aggregate; temperature or weather conditions, etc., that it is almost impossible to give any valuable general data. It is not customary to specify the amount of water to be used, unless the proper consistency and the amount of water required therefor have been previously determined by trial with the materials to be used. The following considerations or points influence the amount of water to be used and must be borne in mind when determining the proper consistency for a given purpose.

Kind and Fineness of Cement.—The amount of water to be used varies slightly with the kind of cement. The amount of water will also vary with the fineness of the cement—the finer, the more water; but this makes less difference, as a general rule, in concrete mixtures than in neat cements and rich mortars. It is very important that Portland cement should have sufficient water for its complete hydration. Natural cement requires less water for hydration than Portland. Cement is a sensitive substance, with a definite capacity for water in the process of hydration, and either deficiency or excess of water in the operation of mixing handicaps the function of the binding medium in direct proportion to the magnitude of the error. *Fine cement will require more water than coarse.*

Character of the Aggregate.—The amount of water to be used varies with the character of the aggregates. Gravel mixtures will in general require less water than broken stone mixtures, since they usually already contain more or less moisture, are less porous, and contain less dust. Large sized aggregates require less water than finer sized. Fine sand mortars will require more water than coarse sand, as the voids are greater; but, on the other hand, they are usually wetter naturally, being, because of their fineness, more retentive of moisture. Mixtures free from dust and fine material, besides the cement, require less water than dusty, loamy mixtures. As the aggregate contains varying amounts of moisture in the different parts of the stock pile, and as the stock pile seldom is perfectly uniform throughout, no hard and fast rule can be laid down for the requisite amount of water.

Porosity of Aggregate.—The amount of water should be greater for porous stone. Some crushed stones absorb more water than others. Sand from absorbent rock will require a larger amount of water. *Dense aggregates require less water than porous.*

Dampness of the Aggregate.—The water should be varied with the amount of moisture in the sand and the stone. Remember always that after a rain less water is needed in the concrete. If the sand and stone were thoroughly wet before mixing, the amount of water would depend largely on the amount of cement in a batch, as moistening of these will lessen the amount of water required to be placed in the mixer. *Moist materials require less water than dry.*

Proportion of the Ingredients.—Lean mixtures require less water than rich ones. The greater the proportion of cement, the more water, since the main function of the water is to put the cement into solution and to hydrate. The minimum of water obviously will be required by the best graded mixture, containing the minimum amount of cement necessary to produce a given result. *Rich mixtures require more water than lean ones.*

Consistency of the Concrete.—The quantity of water required per cubic yard of concrete will vary with the consistency desired (see page 186).

Form and Size of the Molds.—The quantity of water varies also with the form and size of the mold. For molds (or forms) of small dimensions, more water is required, in order that the concrete may properly enter into all corners and surround the reinforcement (see page 190). In forms of large dimensions the concrete can be more readily tamped.

Temperature or Weather Conditions.—The quantity of water varies with the temperature. On a hot, dry day, more water must be used to allow for evaporation (see Art. 32). During dry, hot weather a wet mixture may be used to the best advantage, so as to allow for evaporation. In cold weather, although heated water and heated sand may be used (see Art. 33), there are more chances for freezing with wet than with dry mixtures, therefore a dry mixture is preferable. For disadvantages in using dry concrete, see page 192.

Determination of Proper Amount of Water to Use.—It is inadvisable to lay down any definite rule as to percentage of water to be used in mixing concrete, owing to the varying conditions which obtain. The proper amount of water can be determined only by experience, and must be varied from time to time to suit the conditions of the weather and the nature of the work. The amount of water used in mixing should invariably be approved by the engineer. The amount of water per batch should be determined in consultation with the superintendent, and when so determined the contractor should be required to keep the consistency unvarying. In other words, the water should be measured, and when the proper consistency has been found the same amount for each batch should be used, being varied slightly to suit the conditions of the weather and the nature of the work.

The proper amount of water is that amount which will produce a mixture of the specified consistency—the consistency of the mixture should be carefully watched, and not the dose of water.

The Proper Consistency for Concrete.—This important factor is a matter of judgment and experience on the part of the inspector and

contractor in charge, and changes during a day's work according to local circumstances, dimensions of forms, shape of reinforcement, etc. The behavior of the plastic concrete as it comes from the mixer, and especially while being tamped into place, will with a little practice enable one to judge if the *amount of water* is correct.

The truth about the right amount of water is that the best and strongest concrete is that in which the consistency is that of a thick soup. Soup is of two kinds, bouillon, which is thin and watery, and broth, which is thick. When *soupy* concrete is mentioned it is of the broth and not of the bouillon variety of soup that one speaks. Too much water giving rather too thin a mixture is preferable to too little water giving too stiff a mixture, especially in reinforced concrete, since the surplus water, if not so excessive as to cause the mixture to separate badly, will come to the top, where it may be bailed or swept off, or allowed to evaporate.

Concrete placed around steel reinforcement of necessity has to be mixed considerably wetter than is necessary when placed in large masses. The right amount of water for reinforced concrete is that at which the concrete just quakes when tamped or puddled. At this consistency it will flow properly around the bars. If more water is used the stone can settle through the mortar somewhat as through water; thus the concrete would become of uneven density.

In the opinion of the author, the limit of wetness for many classes of work is not reached until there is so much water that with ordinary care in hand mixing it cannot be made to incorporate with the other materials. The amount of water that will make the best mixture is such that after the concrete has been put in a place and tamped it will quake like jelly when struck with a spade and water will readily come to the surface. If the concrete is much wetter than this the water will have a slight chemical effect on the cement, and, moreover, the sand and cement will tend to separate from the broken stone or gravel.

Excessive Use of Water in Mixing.—Sufficient water should be added so as to make the mixed concrete into a flowing paste that will pour from the wheelbarrow. An excess of water, causing the materials to separate, must be avoided, no more being used than necessary to unite the materials. Very often workmen will go to the extreme and use too much water, making the concrete too wet. It should just show up mushy when tamped or worked into place, and stiff enough so the aggregate will be held in place. If too wet the aggregate will settle to the bottom before the cement sets, thus making a stratum of poor concrete at the bottom of each layer deposited. The concrete is mixed with an excess of water if pools are immediately formed on top of the concrete when deposited in the forms; the pools increase in size, the water finds an outlet to a lower point, and the cement is washed away from the mortar. Inclined "sand-streaks" on the sides of beams, girders, walls, etc., are usually due to this cause. (See page 302.)

Bear in mind that an excess of water weakens the concrete a little, increases efflorescence or laitance (see Art. 31), and retards the

time of setting. Extremely wet concrete which flows nearly as freely as water never develops as great strength as plastic concrete.

Percentage of Water in Concrete.—The following rule (from "Concrete Construction," by Gillette and Hill, page 42, edition 1908) by which to determine the percentage of water by weight for any given mixture of mortar for wet concrete, such as is now most commonly employed, will be found satisfactory:

Multiply the parts of sand by 8, add 24 to the product, and divide the total by the sum of the parts of sand and cement.

For example, if the percentage of water is required for a 1:2 mortar: $((2 \times 8) + 24) \div 3 = 13\,1/3$ per cent of the combined weight of cement and sand. For a 1:3 mortar the rule gives 12 per cent.

In ordinary concrete mixtures dry concrete will require about 3 or 4 gallons of water per bag of cement, 4 to 6 for medium, and 6 to 9 for wet. It may be roughly assumed that 10 gallons of water are necessary for a 2-bag batch mixed in proportions 1:2:4, while 13 gallons will be necessary for a batch of similar size mixed in proportions 1:3:6. Some materials will require amounts of water differing considerably from the foregoing.

The percentage of water required for ordinary dry concrete mixtures (based on the total weight of dry materials) is about 5 to 6 per cent; medium concrete will require about 6 to 8 per cent, and wet concrete will require about 8 to 10 per cent. This is an average of about 1, 1¼ and 1¾ gallons per cubic foot of concrete for the three respective grades. For a wet mixture about 50 gallons of water will be required per cubic yard of concrete.

The exact quantity of water required should be determined by experiment as stated above. Small variations in the percentage of water may produce pronounced results in the strength and gravimetric condition of the finished concrete.

CHAPTER IV

INSPECTION OF FORMS, MOLDS, CENTERING AND FALSEWORK

Forms, molds, centering and shuttering designate the temporary construction required to give to the concrete its shape. Falsework is generally used to designate the supports of forms, molds, centering and shuttering. In considering this subject, the expression "*forms*" will be used to include all the items here mentioned.

In almost all cases it is necessary, in order to confine concrete in place or in the desired shape, to use forms, which prevent it from running or spreading while wet and soft. Wood is usually employed for this purpose, both below and above ground, although occasionally, for small heights, the earth itself is all that holds the concrete in place; but this is not likely to make as good concrete as when wooden forms are used. Sometimes the mold forms a part of the permanent structure, as in the case of masonry piers with concrete hearting, and in steel cylinder piers filled with concrete.

Before taking up the inspection for forms and centering (see Art. 17), something must be said with regard to the material which is best for use in the construction of forms for molding concrete work.

Art. 16.—Lumber for Forms and Centering

The lumber for forms should be of such quality, size and finish that there is absolute stability and perfect work at all times. It should be adapted to the structure and to the kind of surface required on the concrete. The size, thickness and quality of the lumber is generally left to the discretion of the contractor, as it is to his interest to use the best quality of lumber of the necessary dimensions. Whether or not lumber should be planed will be determined by the kind of surface desired. The author is of the opinion that lumber for all forms should be planed on at least one side, as a smooth surface greatly facilitates marking, fabricating and erecting. It will also reduce the labor of removing and cleaning the forms.

Kind of Lumber.—The kind of lumber to use for forms and falsework depends upon the character of the work and to a considerable extent on the available supply in the particular locality in which the work is to be erected. In other words, the kind of lumber which is to be used depends upon whether the material after its first use is to be again employed in similar work, the locality, and the prevailing stocks in the local yards. That is to say, the desired results and price decide to a considerable extent the selection of lumber for forms and falsework.

For the support of the form work, it is the custom to use as cheap a grade of rough, sound lumber as can be purchased. White pine

should be first choice, but, because of its expense, other woods are generally substituted for it, such as spruce, fir, redwood, Southern pine and Norway pine. Some of these woods are more suitable than white pine for struts and braces, although they have a greater tendency to warp. They are, as a rule, stiffer than the white pines. Spruce, in sections where it is readily obtained, is perhaps the best material for studs, joists and posts.

For the form work, or that portion of the work in contact with the concrete, white pine, yellow pine, spruce, Oregon pine and fir lumber are suitable. Some other woods, especially California redwood and chestnut, will stain the face of the concrete. North Carolina pine makes excellent sheathing. Yellow pine lumber is found to be excellent for forms; owing to the large amount of pitch contained, it absorbs water slowly and holds its shape; and because this material possesses both strength and grain of sufficient closeness to prevent badly splintered form boards. Norway pine and fir lumber are also suitable for forms for similar reasons. White pine should be used for cornice and ornamental work, and may be used for fine face-work. For ordinary work, however, even for panels, white pine is generally apt to be too expensive, and other lumber should be substituted for it. Yellow pine or spruce is commonly the best available material.

No hemlock should be allowed in the construction of the form work. It is too coarse grained for sheathing and is liable to split in nailing and to curl on account of the moisture from the wet concrete. In other words, hemlock should not be employed, as it is rough, splintery and weak, except only when absolutely necessary, and then only in the roughest kind of form work. No objection should be made to hemlock braces, studding, and falsework.

Oak is hard to nail, expensive, and imprints grain marks on the concrete even when the form is thoroughly wetted or well oiled. It also warps readily. The hardwoods are too expensive to work.

Quality of Lumber.—The lumber should be free from decay or rot, splits, windshakes, sawed true and out of wind, and square-edged, full-sized, free from large or loose knots or any other defects which would seriously impair its strength or durability. The plank used in the forms should be reasonably free from knots. Knots will show on the finished surface of the concrete and, of course, will weaken lumber which is used for supporting forms. No warping or splintered lumber should be used. All lumber should be subject to the approval of the engineer in charge of the work.

The lumber must not be so dry that when soaked by the concrete it will swell so as to bulge and distort the forms, nor so green that it will shrink so as to leave open joints that will show plainly on the face of the work. Green lumber may give difficulty by drying out and shrinking if left to stand too long before the concrete is placed, thus causing rough joints and considerable rough edges to be dressed down after the work is finished. A slight tendency of this kind, however, may be checked by keeping the boards thoroughly wet with water until the concrete is placed. Kiln-dried lumber therefore is not suitable for form construction because of its tendency to

swell when soaked by the concrete, and green lumber is undesirable on account of liability to check and warp. Partly seasoned lumber or dried stuff is therefore the best. When it comes to a choice between green and dry lumber, green lumber is preferable because it is less affected by the water in the concrete. However, it is best to use a natural and well seasoned material as mentioned above, taking care not to drive the work up too close, and to saturate the forms thoroughly several times before the concrete is placed (see Art. 18, page 240). By doing this the best results are apt to be obtained.

Thickness of Lumber Used in Form Work.—Regarding the thickness of lumber used for forms, custom differs with contractors and localities. In fact, contractors differ greatly in their ideas of the proper thickness of lumber to use for various parts of form work.

The thickness of the lumber should be such that it will not deflect, bulge or warp under the loads imposed upon it. Lumber should be straight and true and of even thickness. This is generally advisable for convenience in handling. Wide boards should not be used for sheathing, for the reason that they curl and split badly. Amply thick and heavy material should be used for forms, especially if they are to be used a number of times. Thinner material is easily broken, thus requiring more labor for repairs than would pay for the extra thickness. Thick planks will hold their shape better and last longer. Figured in commercial thicknesses, measured before planing, in some cases a 1-in. thickness is used, in others a 1½-in. thickness, and in a few others a 2-in. thickness, even for such work as panel forms.

If the forms are to be used only one time, they are usually made of 1-in. dressed material; whereas, if they are to be used several times, the side and bottom form boards of the beams and girders (see page 219) are made of either 1½ or 2-in. dressed planks, because these usually withstand the successive operations of demolishing and erecting much better than the lighter material. Generally speaking, 1-in. stuff is used for floor lagging with joists spaced up to 24 in., or when built into panels; for column and wall lagging 1¼ to 2-in. stuff is used; for sides of beams and girders 1, 1¼, 1½ and 2-in. stuff is used; and for bottoms of beams and girders 1½ and 2-in. stuff.

Sizes of Lumber Used in Form Work.—The shores and supports for the centering generally consist of rough 4x4-in. studding, it having been found by practice that such studs, when placed from 4 to 6 ft. on centers, possess the necessary strength to carry the weight of the wet concrete for usual floor systems. For ledger boards, cross-braces and ties, as well as for nailing strips and battens, 1x6-in. or 1½x6-in. sawed boards are found convenient; 2x6-in. and 3x6-in. joists are used to some extent for the support of slab centering and for the bracing of the supports. These dimensions are by no means invariable, as a study of the numerous examples of actual form work given in *Engineering and Contracting, Engineering News, Engineering Record,* and many books on plain and reinforced concrete construction, will show. Timbers as large as 4x6-in., 6x8-in. and 8x10-in. are used

to brace and secure the form work for heavy concrete wall and buttress construction, and all sizes of timbers are used for the falsework of concrete arch construction.

Dressed Lumber for Finished Surface.—Dressed lumber should be used where finished surface is desired. In other words, the form boards used on all exposed surfaces should be of dressed lumber and closely fitted in order to secure the best results in appearance and surface of the finished work. On the other hand, wherever a surface finish (see Art. 43) is to be used, rough lumber can be used on that side. The lumber for face work should be surfaced on one side and two edges and dressed on the face side to even thickness, and may be tongue-and-grooved flooring or similar lagging. Tongue-and-grooved or beveled-edge stuff gives the best results for floor and wall forms. Tongue-and-grooved boards, however, are more expensive than boards surfaced on one side and the edges, which will generally answer for most work. A principal objection to the use of tongue-and-grooved lagging is that there is no opportunity for it to expand, and, again, the planks are particularly hard to place a second time.

Undressed Lumber for Rough Work.—For backing and other rough work, undressed lumber may be used. Undressed lumber should be used where the concrete is to be plastered (see pages 410 and 442). In other words, forms for non-exposed surfaces may be rough lumber but should be water-tight. However, for rough concrete work it is generally best to use lumber for sheathing that is dressed at least on one side and two edges (as mentioned above for finished surfaces), to make the boards of uniform width, so that they will fit together. Even if the appearance of the concrete is of no account, the smooth form surface will reduce the labor of removing and cleaning the forms.

Use of Old Form Lumber.—Frequently the contractor is compelled to use old material for the form construction; that is, material that has been previously used in reinforced concrete work. Such lumber must be thoroughly cleaned before it is again built into forms, and, if necessary, the sides and ends must be freshly jointed so as to make a perfectly smooth finish to the concrete. Care must be taken to see that badly split and splintered lumber is properly patched up and gotten into good shape previous to constructing the forms.

Inspection and Rejection of Form Lumber.—The lumber should be inspected when received, and any lumber unfit for use in forms should be rejected immediately.

Care of Lumber for Form Work.—The finish of concrete construction depends largely on the kind of lumber used in the forms. Therefore the lumber for this purpose should not only be well seasoned, as mentioned above, but when delivered should be properly protected.

Art. 17. Fabrication and Erection of Forms and Centering

Form work depends on the type of construction and required alignment of the completed structure. In the erection of reinforced

concrete work nothing requires more careful consideration than the construction of the form work, or molds, necessary to shape and support the concrete until it has thoroughly set and hardened. As the function of the forms is to secure a suitable receptacle in which to mold the concrete, it is of the greatest importance that they should be constructed with the utmost care. In other words, forms are an important medium for making concrete, and too much study cannot be given to this part of the work.

Supervision of Form Construction.—Many designers leave the details of the construction of forms and centering to the contractor, working on the supposition that if the specifications require a certain standard of work when finished, the contractor will use his best efforts to secure this result. Such a supposition is far from being the case, for the contractor usually will take greater chances during the construction than is always good for the work. Experienced contractors generally do exercise thought in constructing the forms, so that the results of the finished work may be very satisfactory; however, the architect or the engineer will do well to exercise a supervision over their construction. In all instances the architect or the engineer should control the time for the removal of the forms (see Art. 19), and should be capable of insuring the safety of the structure by intelligent inspection of the falsework and supports.

The safety of a reinforced concrete floor, as well as that of the entire structure, may be jeopardized by faulty form construction. Wooden forms, as frequently erected for reinforced concrete work, upon careful inspection show a great many weaknesses, inadequacies, and the factor of safety which exists is surprisingly low. In fact, many of the failures of reinforced concrete construction can be traced directly to weakness in the forms due to faulty construction of their supports or the falsework. Much time should therefore be devoted on the job to the inspection of the forms, both during erection, concreting, and removal, to insure against costly errors. The greatest vigilance is required of the inspector to see that the forms are properly constructed, no matter whether an experienced or inexperienced contractor is doing the work. Not long ago a building collapsed with the centering still in place. The claim was made that some blasting was done which shook the structure so much that it collapsed. That was a very clear indication that the centering was erected in an extraordinarily lax manner. A very careful inspection should be made of this point.

Labor.—It is desirable that skilled labor be employed on form work and competent foremen are necessary. One man in each gang must be in charge of it, under the head carpenter or general foreman.

GENERAL REQUIREMENTS

Type of Forms.—Throughout the practice of reinforced concrete construction various methods of form construction are in use. Generally a particular type of form work will be found to be confined to a locality, or else will be used by a single firm of reinforced con-

crete contractors, the advocates of the several systems believing the system that they use to be the best and most economical. As a rule, the contractor should be allowed to use such type of forms as he may desire, if, in the opinion of the engineer, the proper results will be obtained. If, however, it is apparent to the engineer that the forms are not properly constructed so as to give the desired results, the contractor should be required to make such changes as the engineer may deem necessary to give satisfactory results.

Approval of Form Details.—Plans and details for forms, if required to be furnished by the contractor, should be submitted to the engineer for his approval before starting the form work, but such approval should not release the contractor from any responsibility for the safety of his work and the work of other contractors.

Pressed Steel Forms.—Metal forms may be used to advantage for the erection of small buildings, sewers, conduits, etc. They are used to a limited extent in concrete column, girder and slab construction. Steel forms should be of acceptable design. They should be so rigid as to permit making the faces practically true planes in conformity with the plans, with a variation of not more than $\frac{1}{4}$ in. The chief difficulties in the use of metal forms are their liability to leakage, tendency to rust, and possible injury by dents in removing.

Economy in Form Construction.—Forms should be constructed with a view to economy in taking down rather than cheapness in erecting or in first cost. Greater economy will result in using forms over and over again than in using poor lumber which rips to pieces when taken down, and unless they can be used many times they are apt to be the largest single item of expense on a concrete building. In fact, the greatest economy is gained by constructing the forms so that they can be used over and over again in the structure. With a little ingenuity and forethought, this work can be most always arranged so that repeated use is made of each piece of lumber. It is not unusual to construct a ten-story building by using over again the form work employed for the first three stories. It requires a great deal of study frequently to design the forms so that they can be so used, but it means a great deal of money in the contractor's pocket.

If forms are to be used repeatedly, oiling will do much to prevent the absorption of water and shrinkage, and will enable them to be removed readily (see Art. 18, page 241). Even for rough forms, plank planed on one side may be economical to cheapen cost of cleaning. For repeated use in built-up sections, tongue-and-grooved lumber is to be preferred, or the forms may be covered with galvanized sheet steel as mentioned below. The latter is preferable where a smooth finish is desired.

Workmanship.—Forms should be constructed by experienced and capable workmen only, and must be of first-class workmanship throughout. Defective workmanship upon forms for reinforced concrete work means not only unsafe work but unsightly work as well. All forms should be fabricated, put up and removed in a manner satisfactory to the engineer. (See page 381.)

Loads on Forms.—All forms should have ample strength to support

properly the loads they are called upon to carry. They must be strong enough to retain wet concrete, or they must be strong enough to withstand the pressure due to tamping in case a "dry" concrete is used. Loads on forms must be restricted to those for which the forms are designed. These loads generally comprise the weight of the concrete and such necessary construction loads as the weight of workmen, runways, wheelbarrows, etc. Storage of construction materials for future use on the forms should not be permitted under any circumstances.

Fabrication of Forms (Accurate Measurements).—Plans, if provided, should be followed exactly or else altered with the approval of the engineer before work on them is begun. All form work must be constructed accurately to the framing plan. All measurements must be accurate, the lines true and square, the joints close, and the finish done in a neat and workmanlike manner. One of the difficulties in form construction is in setting the forms true enough to line and level to avoid a lot of subsequent labor straightening and adjusting (see page 211). This trouble is largely due to inaccuracies in making up or fabricating the forms. If the widths of the column forms are exact and the beam forms are cut to exact length, the wall columns must come plumb and true. A maximum variation of ¼ in. only should be permitted from the sizes shown on the drawings. Forms should be finished to the exact height on top. Particular attention should be given to the piecing-out of beam boxes, the alteration of column forms, etc. All forms should be arranged so as to be taken down in proper order without injuring the concrete. Cutting of the lumber should be avoided as much as possible. Extreme care should be taken to reinforce corners of the framing.

Lining Forms with Sheet Metal.—If very smooth concrete work is desired, the wooden forms are sometimes covered with sheet metal. Black sheet iron has been used for this purpose to some extent, although galvanized iron is preferable for the lining of forms, because the concrete adheres more strongly to black plate than to galvanized iron, and, besides, the plate is liable to rust and stain the work. Tin is occasionally employed. Zinc should never be used, as it seems to attack the cement chemically.

Forms lined with sheet metal will show a wave appearance unless heavy material is used. Generally No. 27 gauge galvanized iron is used for the lining of forms. Sheet metal of No. 20 gauge (0.035 in thick, 1.42 lbs. per square foot) has been used for this purpose, but where the same lining is used several times a heavier sheet metal is preferable.

A great many engineers object to covering wooden forms with sheet metal, as the metal is liable to break and tear when removing, and if the form is strained in the handling the metal covering makes it harder to put back in shape. In fact, if sheet metal is placed on a wood back or even a metal stiffening frame, there is danger of its becoming dented, bent, or otherwise defaced so as to give an imperfect surface to the concrete; and if the metal covering is sufficiently

thick to resist damage it is too heavy and too expensive. Another objection to lining forms with sheet metal is that nail-heads will show. The nails should be placed only around the edges of the sheet metal, which, if cut to a predetermined size, may have the edges covered by bevel pieces to give the finished surface the semblance of cut stone (see page 415). The joining of one sheet of lining to another may present greater difficulties than the joining of planks, but joints will occur less frequently.

If metal is necessary to permit easy removal or to give the concrete surface a smooth finish, a complete metal form may be used as mentioned above.

Lining Forms with Building Paper.—Forms are sometimes lined with building paper. The use of paper needs constant attention in order to secure satisfactory results. It is somewhat difficult to keep the paper absolutely smooth, so that the final surface does not show wrinkles. The paper is easily torn in placing reinforcement and in shifting the forms, requiring much patching. (See page 226.)

Water-Tight Joints.—All joints in forms should be fairly tight, being close enough to prevent leakage of the liquid mass which will bleed the concrete of any material portion of its contents. In other words, the forms should be built as nearly water-tight as practicable to prevent a gross leakage of mortar. The leakage of water colored by cement should not be considered injurious. This precaution regarding water-tight joints applies to forms for wet concrete, as dry concrete does not require tight forms, since there will be no liquid mortar to run out of the cracks; but where a wet mixture is used, poor joints permit the escape of water cement, thus marring the appearance of the finished work by leaving holes.

Stopping of Joints or Covering Cracks in Forms.—Cracks in forms into which the mortar will force itself and form "fins" on the surface of the work must be avoided. The stopping of joints in forms is accomplished partly by the use of water to cause the wood to swell and partly by filling the joints with some material. Cracks in forms may also be covered with sheet iron, but the use of paper for this purpose should not be permitted, as it swells when damp and sticks to the concrete surface when the cement sets, so that it is almost impossible to remove it. It is also very difficult to keep the paper smooth, so that the final surface does not show wrinkles. Cracks or joints in forms may be closed by putty or clay, plaster of Paris. oakum, cotton, or strips of wood. The use of fire clay to close knot-holes, etc., is recommended. Hennebique made some of his forms with open joints and afterwards covered them with canvas, which absorbed the excess of water and gave a uniform surface finish to the concrete.

If necessary to obtain tight forms, caulking with oakum or other suitable material may be permitted. When thus treated the swelling of the boards does not cause trouble. Caulking of ¼-in. Manila twine may be used to make forms tight at joints, if preferred by the contractor, or a plain point may be made. It will sometimes be found that considerable time can be saved and better results obtained

by going over the forms by caulking and smoothing defective joints with plaster of Paris, instead of oakum, as is usually done. In fact, plaster of Paris has been used with great success for filling cracks or joints. The plaster of Paris should be mixed thin enough to pour. One man generally goes over the forms, filling cracks and nail-holes, and another follows about fifteen or twenty minutes later, scraping off the excess plaster with a trowel. The forms are then lubricated in the usual manner (see Art. 18, page 239).

Clay is very commonly used for stopping joints or cracks in forms. A clay of some sort can generally be found in the vicinity of every concrete job, and it takes very little time to mix it with water into a tough paste and fill all cracks. One objection to clay is that when a long time intervenes between the placing of the clay and the pouring of the concrete the clay dries up and falls out. This objection may generally be overcome by using thin oil with which to mix the paste instead of water. Thin soap or very heavy soapy water may also be used. This is cheaper than oil and much more readily mixed with the clay. Some fiber or hair similar to that used in plastering mixed with the mud paste makes it possible to use it in filling quite large cracks, although the use of fiber or cow-hair is not common.

Improving Edges in Joints of Forms.—In all cases where it is evident that the joints between the individual boards of the forms will provide an excessive roughness, or unsightly board marks, in the exposed concrete, the edges of said joints of the forms should be removed and replaced or otherwise improved and repaired before concreting. In case two or more end joints in adjacent planks are in the same vertical plane, special precautions should be taken to prevent a lip or fin on the concrete. The edges of the plank should be dressed with a slight bevel, so that the planed surface is the widest. This is done to insure a tight form. (See page 382.)

Finish of Forms for Exposed Concrete (for Particular Work).—The finish of the forms depends upon the degree of finish called for in the specifications. If the concrete is to show a smooth surface, the surface of the forms in contact with it should be smooth. In other words, the surface of the forms in contact with the concrete should be prepared in accordance with the requirements of the specifications.

All exposed concrete (unless otherwise specified or desired) should be made the subject of extra care, the forms being made from either tongue-and-grooved or bevel-edged stuff, free from knots and split edges, with all joints driven tight and securely nailed, and all imperfect pieces removed or properly repaired. If matched boards are not used it is a good plan to chamfer one edge of the boards so that the joint will close tightly when the wood is wet. Many concrete experts advise the use of bevel-edged stuff in preference to tongue-and-grooved, as there is no opportunity to expand when planks of the latter swell. The advantage of chamfering the lower edge of side boards is that if the planks swell on account of being wet each plank can slide past its neighbor and none of them will warp or spring.

This refinement is, however, not often used in practice, except in reinforced concrete work.

Joints should be made perfectly flush after they are built in place, by planing off any unevenness or projections that occur; and any openings at joints or corners, or any knot holes or other voids, should be plugged flush with some stiff, plastic substance, such as fire clay mixed with plaster of Paris or sand (see also page 204). The removal of the board marks is possible under one condition only, and that is that all joints between boards must be tight. The joints fill with the finer parts of the mixture, especially with cement, so that the small ridges between the boards are rich in cement. It follows that the concrete immediately behind the ridge is leaner in cement than other parts of the surface, and it is therefore softer than the surface generally, so that any mechanical treatment of the surface (see Art. 43) removes too much at the ridges, forming small grooves looking almost as bad as the original ridge. Hence, the joints must be tight, so that no cement can ooze out, and fairly smooth, so that few and small ridges only are formed. Some specifications require that if cracks open more than 1/8 in. the forms shall be rebuilt. No tin patching is recommended.

All face boards should start horizontally and be kept horizontal by drawing the boards down with a wedge, and each board should be securely nailed to every stud or to the cleats to prevent spring. The carpenter work must be good and the forms made of good lumber.

There is no practical difference in the appearance of concrete, whether wood, sand, galvanized iron, cast iron or plaster of Paris is used in the face work forms.

Lagging and Studs.—Studs should be of sufficient size and so spaced as to prevent the lagging or sheeting from springing between studs. As a rule, the spacing of studs for 7/8-in. boards is 2 ft.; for 1 1/8-in. boards, 3 ft. 6 in.; and for 1 3/4-in. boards, 4 ft. 6 in. The studs run from 2x4 in. to 4x6 in., according to the span, and 4x4 in. and 4x6 in. are the most common dimensions for posts. The studding for all work should be dressed or sawed to an even thickness in order that the alignment may be perfect.

The lagging should be surfaced, of uniform thickness and suitable width, and of selected material, and the edges surfaced so as to form tight joints when put in place, the object being to obtain concrete structures with even surfaces and true alignment. All lagging may be tongue-and-grooved or bevel-edged, as desired. The planking forming the lining of the forms should invariably be fastened to the studding in perfectly horizontal lines. The ends of these planks should be neatly butted against each other, and the inner surface of the form should be as nearly as possible perfectly smooth, without crevices or offsets between the sides or ends of adjacent planks.

Bolts and Sleeve Nuts.—Forms may be held in place by means of bolts so made that the outer 3 in. of the bolts can be removed after the forms are taken down, and the remaining holes filled with 1:2 or 1:3 mortar. This may be accomplished by sleeve nut connec-

tions which will permit the removal of the projecting ends of bolts or rods, etc., leaving only small holes in the concrete, which can be stopped with mortar in the above or any desired proportions. Rods should be cut from 2 to 4 in. shorter than the space between the forms, and threaded, with a pump-rod coupling placed on the threaded ends. Stubs threaded at both ends will finish out the bolt. When the forms are struck the stubs may be screwed out of the concrete and used again. The small hole left by the stub is easily filled with mortar by the finishing gang. Sometimes it is desirable to remove the entire bolt, and in such cases the bolt should be coated with heavy grease or other means taken to prevent adhesion of concrete to the bolt. Bolts must be absolutely straight, or it may be impossible to remove them. Washers should be used under all bolt-heads and nuts, and before proceeding with the concrete work forms should be brought true to line and grade, and all bolts should be taut.

The use of bolts will be discussed more freely under wall forms (see page 229).

Use of Spikes and Nails.—Forms and centering should be constructed in such a way as to avoid the use of nails whenever possible. Sections to be used over and over must be securely nailed. On the other hand, forms to be taken apart should have as few nails as possible, using cleats and wedges or other clamping devices in preferance to nails, spikes and screws. Boards and planks need but few nails unless the forms are built so that pressure tends to separate them from the cleats. The pressure of concrete will generally hold temporary panel boards in place with scarcely any nailing. The sheathing of wall forms, for instance, if to be removed board by board, requires only enough nails to take out the wind of the boards and hold their own weight till the concrete is placed. In other words, spikes and nails should be used sparingly. Every nail that is driven gives trouble when the forms are taken down to be replaced elsewhere. Unnecessary nailing not only calls for more nails, but adds to the difficulty of removing and the danger of splitting and ruining the boards. Braces are seldom less than 1 in. thick, and it takes hard driving to get spikes through them. Whenever possible, blocks or wedges held in place by thin nails should be substituted for the large spikes so often employed, or clamps should be used, as the lumber will be rendered unfit for continued use by repeated spiking or heavy nailing.

In building forms, do not drive the nails all the way home. Leave the heads out, so that it is possible to draw them with a claw-hammer without injury to the lumber. A special form of double-headed nail designed for easy pulling is now on the market. These double-headed nails can be driven home and will hold more than the ordinary nail, owing to the large area of the square washer, or the "second head," as it is termed. When the forms are to be taken down, the nails can be removed without injury to the lumber, and, if carefully driven, can be used indefinitely.

All temporary nails should be removed just before the concrete is

poured, so that portions of forms intended for easy removal will not be found tightly nailed when the workmen are ready to strip them. The less hammering done around green concrete, the better.

The skillful foreman may be easily recognized by the scarcity of spikes and nails he uses. The pride of every foreman should be to have his forms removable and collapsible, so as to be compelled to pull as few nails as possible in aligning or shifting them. If the removal of centering necessitates the use of the long prying crow-bar with three laborers at its end, the foreman should be discharged. Forms and their supports are often nailed or permanently put together, requiring costly effort to detach them and too frequently the use of the sledge and iron bar, the latter levering against the new concrete and badly marring it, as well as unnecessarily injuring the forms themselves.

Wire Ties.—Wire ties may be used to secure forms against pulling apart. They may be wound around opposite studs and then twisted with a stick, as a turn-buckle, until the studs are the proper distance apart. To remove the forms the wires are cut and then trimmed very close to the concrete surface. The use of wire ties will be discussed more fully under wall forms (see page 229).

Steel Clamps.—Adjustable steel clamps for clamping and adjusting forms should be built on practically indestructible lines, giving rapid readjustment in all classes of forms. Clamps should be removed without the use of crowbars, hammers or other tools. Heavy C-clamps may be used to secure forms against pulling apart. They will be found to be better than bolts or tie rods for column boxes and beam forms.

Bracing of Forms.—All forms must be securely braced to withstand the loads that come upon them and preserve their alignment, but the braces should be designed to resist all tendency to slide, and may be useless if put in without thought. Wooden pieces may be used for this purpose, generally 2x4-in. scantling. Wire ropes should not be used, as the stretch in these may be disastrous to the structure. Braces should be firmly fixed at the foot and top, and as many braces and supports used as may be necessary to prevent deflection from the working of the concrete. In other words, the posts and braces should be of sufficient strength to make a practically unyielding support to the sheathing. Several methods of bracing forms for heavy concrete work may be employed, as follows (in this connection, see also Wall Forms, on page 227):

(1) With outside inclined braces, leaving the interior of the form unobstructed.

(2) Tie-rods across the interior of the form, connecting opposite posts at frequent intervals.

(3) Each post trussed vertically and tied across at top and bottom only.

(4) Horizontal trussed walls outside of posts, spaced 4 to 6 ft. apart in the vertical and tied across at the ends.

Inclined Braces.—If thin braces are employed they should be in

pairs, one on either side of the vertical post, and made to act together by cross-pieces nailed to the two planks.

Bracing Forms with Cross-Ties.—Another method of bracing forms is to construct them with cross-ties between the front and back, these ties to be placed at frequent intervals above the lower portion of the form and to be removed as the concrete is built up, the studding out of which the forms are constructed being sufficiently long to extend above the top of the finished masonry, and at least one set of ties being used above this level.

Construction of Forms in General.—Forms should be so constructed that they can be removed without injury to the concrete, and they can be erected accurately. Construction which necessitates the use of heavy crowbars or hand-sledging to take the forms apart should not be permitted. In other words, the forms should be so secured at all parts as to permit their removal without danger of injuring the concrete in any way. Care in the construction of the forms shows materially in the appearance of the finished work. It is usually found that the care and judgment displayed in the construction of the forms is a criterion of the entire construction, and that the results of care in this work will insure a safe structure and a fine, clean appearance.

Erection or Arrangement of Building Forms.—The arrangement of forms and centering in building construction should be such that the slab centering and sides of beams, girders and column forms can be removed first and then allow the bottom of beams and girders to be supported for a longer time. The forms will thus be left a longer time under members subjected to the greater stress. In erecting forms, building lines must be carefully preserved by means of strings stretched between the points previously accurately set by surveyor's instruments. Erect, line and plumb the column forms first (see page 214); then erect, line and level the beam and girder forms and set the beam and girder staging (see page 219), and finally erect and level the slab centers and their supports (see page 221). Forms should be erected in such sequence as to allow the contractor to lay out his work so as to reduce the walking over and on setting concrete, to a minimum (see page 334). This is an important caution and by rights is worthy of being placed on a large sign on every job.

The forms should be so constructed, in all cases, as to leave proper niches, grooves, opening and brackets in the concrete, for supporting the ends of the beams, edges of floors, and ends of walls, etc.

Swelling of Forms.—Forms should be so framed that swelling will not fracture the concrete or prevent easy removal. Care must be taken to prevent work from being thrown out of plumb by swelling of lumber in forms. If the forms spring out of place, the concrete may flow out and be wasted; and, at best, any springing of the forms will injure the appearance of the surface of the finished structure. The boards should be planed or bevel on one edge, the full width being against the concrete, in order to prevent excessive pressure and heaving of forms due to swelling. The narrow edge

of a board will then be brought in contact with the wide edge of the next, and so on. A closer fit will then be secured. In this connection, see page 205.

Openings in Forms.—All forms should be so constructed as to be readily accessible for inspection at all places and at all times and to be easily cleaned. Openings should be provided in the forms at the proper places so as to permit of the ready inspection and cleaning of the spaces to be filled with concrete (see page 285).

All openings in forms must be effectually stopped to prevent the escape of water so far as practicable. For stopping holes in the bottom of forms, pieces of tin may be used. They can be made from old tin cans or obtained from a nearby tinshop, and short nails can be used to fasten them over the holes. Care must be taken to see that the tin is properly centered over the opening and that no cracks are left, in order to prevent leakage or escape of mortar from the concrete. For holes cut in upright forms (columns, for example) a secure plug may be made of a piece of wood, a little smaller than the hole, with a piece of tin fastened to it and projecting over the edges. This is inserted in the hole with the tin on the inside and a small wedge placed between the side of the plug and the edge of the hole will hold it in place until the concrete rises to that level, after which the pressure of the concrete will hold it.

Beveled Corners in Forms.—Sharp corners should be avoided, especially on exterior angles, as it is difficult so to tamp the concrete as to make the corners perfect, and they are very likely to be chipped off. In fact, square corners are contrary to the nature of concrete. Projecting corners are difficult to make in the first place, as the concrete seldom penetrates to the very apex of the angle; and, in the second place, they are liable to injury both when the forms are removed and while the concrete is green. Once broken, they cannot be repaired so that the patch looks like the balance of the work (see page 341). The re-entrant corner is easily made but objectionable, for the reason that a sharp dent in the concrete very often forms the starting-point for a crack which might otherwise have been avoided. Very often the form is locked to the concrete by a sharp corner so that the workmen use too much force in removing the forms. Broken corners are the great drawbacks in concrete construction; they may easily be avoided by chamfering the forms so that all sharp angles are excluded.

In other words, corners of forms should be beveled or filleted whenever possible, in order to facilitate their removal and to improve the appearance of corners in the concrete. Beveled or rounded corners may be made by introducing the proper triangular strips or round-corner molding pieces within the forms. This is generally done by cutting 2x2-in. stuff diagonally (or in some cases 1-in. stuff is cut diagonally), or, for round corners, by tacking 1½-in. hollow quarter rounds in the corners of forms. All exposed corners should invariably be beveled unless otherwise required. In other words, wherever there is no conflict with specific details, salient angles should be filleted and re-entrant angles chamfered. Triangular strips

across the end of planks or boards prevent the end grain of the wood showing on the finished concrete.

When beveled or rounded edges are specified, care must be taken to see that the proper beveling strips or moldings are placed in the forms. This is a minor detail, very likely to be overlooked by carpenters.

Triangular strips or round-corner molding pieces should be thoroughly secured to the formwork from the inside to prevent being misplaced in the depositing and tamping or puddling of the concrete, and should be saturated with water to prevent swelling, with resultant injury to the concrete.

Water Drips.—Water drips on projecting ledges of abutment copings, window-sills, etc., may be formed by nailing a small half-round to the upper surface of the form a short distance back from the projecting face. A ridge is thus left at the edge of the under side of the projection so that water is compelled to drip from the edge and not follow back to the main face of the wall.

Expansion Joints.—Beveled strips of wood may be inserted vertically (or horizontally, as the case may be) at every expansion joint, leaving a notch about 1½ in. wide and ¾ in. deep, thus avoiding irregular and saggy contact. (See Art. 28.)

Provisions for Pipes, Shafting Hangers, Etc.—Cores must be provided in forms for wiring, pipe, and for any other purposes, as shown on the plans or as may be directed by the engineer in charge. Ample provisions must be made for shafting hangers in industrial buildings. In building forms for foundations, walls, etc., care must be taken to provide chases and opening for all pipes, etc., and where any wood is to be fastened to the concrete, to build in bolts with nut end sticking out from the face of the wall a sufficient distance to bolt up the woodwork.

Forms Exposed to the Weather.—After the forms are built they should not be allowed to stand long in the sun or be exposed to the weather before being filled with concrete. Sun and wind will destroy the best made piece of form work. Long exposure will throw the surface out of true and open up the joints. Forms likely to be exposed to the weather for some time should be kept wet in order to prevent the form work from being twisted out of shape. The false-work must be protected against rain or snow. When it is found necessary to leave the form work empty for any length of time it must be gone over very carefully just before pouring the concrete, the open joints repaired, and the bracing and supports tightened up (see Art. 24).

Alignment of Forms.—All forms should be erected as far as possible in exact alignment, both vertically and horizontally. One point in setting forms and falsework is of the greatest importance, and that is to see that all verticals are absolutely plumb and maintained plumb. Column and wall forms should be plumb. Girder boxes and wall forms should be without winds or twists, and floor slab centers should be level, etc. Accuracy in level is somewhat more difficult to obtain if the forms are set upon concrete which is not absolutely smooth, and, in such cases, they must be brought up to

line and level by wedges or other suitable devices. Lining girder forms and lining and plumbing column and wall forms is high-class carpenter work and should be done by a few careful or competent carpenters, and the rank and file in the form gang should be required to keep the lines fixed. A column or girder which is out of line or plumb not only looks bad but may be required to be removed and corrected by the engineer. The expense for one such correction will be many times that which would have been involved by proper care in the first place. In some cases, especially in a large building, labor is saved by leveling up the forms with an engineer's leveling instrument.

If the forms stand any considerable time between erection and time of depositing the concrete, the lines and levels should be checked just before placing the concrete, to see that the forms have kept their shape. The alignment should also be checked after storms and high winds. The alignment should be maintained during the placing of the concrete. In other words, before pouring concrete all forms should be instrumentally tested for position and horizontal and vertical alignment, as they *must not* be disturbed after the concrete is in place. Warped forms should be rejected. The lines and levels of all forms must be checked by the contractor and be brought to the correct lines and levels immediately before concreting. Keeping of forms plumb is the most difficult thing which devolves upon the contractor. Forms may be provided with jacks or other suitable device to permit realignment during the progress of the work. Any extra expense incurred by faulty alignment or undue irregularities must be paid by the contractor.

During the depositing of the concrete (see Art. 25) there should be men at hand whose duty it shall be to notice when forms give way and rectify the trouble at once. The author has made it a practice to have two good carpenters do nothing but watch the alignment of the forms for columns, beams, girders and slabs by driving and setting wedges or placing such shims inside the column braces as may be required. Not only the foreman but every man on the job should be on the watch-out for alignment in both directions.

Workmen may err on the side of poor alignment or more careful alignment than the structure requires. Mr. W. J. Douglas* suggests as a general rule the allowance of "⅜-in. departure from established lines on finished work and 2-in. on unfinished work." The latter may be increased indefinitely, depending on the size and nature of the work, but as a general rule the forms should be within 2 in.

Rigidity of Forms.—Forms should be thoroughly braced or tied together so that the pressure of the concrete, or the movement of men, machinery or materials, will not throw them out of place. They should be of sufficient rigidity that the vibrations may not be severe enough to affect the setting of the cement. Rigidity is as important as strength, and deflections of forms should be limited to very small amounts. In calculating forms, particular attention must be paid to deflection even more than strength.

* *Engineering News*, Dec. 20, 1906, page 648.

Wherever, in the opinion of the engineer, forms are not sufficiently stayed and braced or of sufficient strength in any way, the contractor should be required to make such additions and changes as the engineer may direct at the contractor's expense. In other words, forms should be amply strong to resist the pressure which will be brought upon them, namely, the ramming of concrete against their faces and the static pressure of the semi-fluid mass in the case of concrete laid wet. As the concrete is being put in place, the forms should be carefully watched for breaking or bulging. If the forms do spring under the weight of the concrete they should be immediately braced to prevent further springing, but no attempt should be made to straighten them, as concrete should not be disturbed after it has commenced to set. A great deal of work is badly marred by the lack of rigidity in the forms.

Removing Forms for Finishing.—Where the surface is to be finished by scrubbing (see Art. 43, page 397) or other process requiring the concrete to be still green or before it is about a week old, proper provision must be made, in the construction of the forms, for laying bare the concrete as fast as it reaches the required hardness. The forms should be bolted and fastened together so they can be taken down without jarring the concrete and cracking and chipping it.

Supply of Forms.—Sufficient forms should be furnished by the contractor to permit of pushing the work rapidly; and if at any time the proper rate of progress is retarded by lack of forms, additional forms should be provided. That is to say, the contractor should be required to provide a sufficient number of complete sets of forms for the construction to proceed without interruption. In other words, no delays caused by waiting for concrete to harden before removing forms should be permitted, unless absolutely unavoidable, and sufficient form material must be provided to allow the concrete to progress without interruption. There should be no objection to allowing the contractor to use the forms from a finished floor for the construction of an upper tier, provided it does not necessitate the removal of the centering.

Fitness of Forms.—The fitness of forms for use at all places and at all times should be carefully judged by the inspector, and he should see that his orders respecting the bracing, supporting and wiring, as well as the cleaning and wetting (see Art. 18), redressing or replacing of the forms are strictly followed. Deformed, broken, defective or otherwise imperfect forms or centers should be repaired and made satisfactory, or should be ordered removed from the work. The inspector should take no chances and should not be governed by the desire of the contractor or owner to push the work beyond safe lines. He should report to the engineer in charge of the work any undue cutting of washers into the forms. He should also report all form rods which have broken under the strain of the concrete.

Responsibility for Accuracy or Sufficiency of Forms.—The inspection of forms by the engineer or his authorized representative during or after the process of construction, or any suggestion or assistance furnished by the engineer, should not be construed as relieving the

contractor of the entire or any part of the responsibility for the accuracy or sufficiency of any of said forms or for the satisfactory completion of work to any extent dependent thereon.

Forms for Winter Concrete.—If concreting is done in freezing weather the forms may have light sheathing outside of the main vertical or horizontal beams or walls, or otherwise so arranged as to permit heating the main sheathing to a temperature of at least 35° F. and maintaining this temperature until the forms are removed and the finish completed. (See Art. 33, page 362.)

Protection of Form Work.—The contractor should be required in all cases to use proper care and diligence in building his forms and in keeping them plumb, straight and true (see page 211) and in bracing and securing all parts of the work against wind, storm and frost, inasmuch as they may interfere with the stability and perfection of the work; also in all cases to judge as to the amount of diligence and care required for the same. In this connection, see page 201.

Rejection of Forms.—Should the forms lose their proper shapes and dimensions, or should the surfaces become unduly roughened or dented, satisfactory forms must be substituted. In other words, forms or centers shall be replaced by new ones when they lose their proper dimensions or shapes, deformed or defective forms being removed from the work.

COLUMN FORMS AND BRACES

Column forms should be so constructed as to permit of their removal without disturbing the beam or slab forms. In removing forms the column molds are taken down first. It is therefore necessary to so design the details about the tops of the forms as to permit of their removal without in any way disturbing the beam and slab forms. Forms built complete a full story high and concreted from the top are essential where wet and sloppy concretes are used (see page 187). For columns it is necessary to make a form for each side and to hold the forms together by bolts or strong wires so spaced as to prevent any distortion. Forms may also be held apart with separators which can be easily removed as the work progresses, or which may be incorporated in the concrete without injury to it.

Thickness of Lagging.—Column forms vary in thickness from 7/8 of an inch to varying greater thicknesses. They should be made up with plank not less than 1 in. thick, preferably 1½ in. thick. However, for lagging, 1¼ and 2-in. plank are commonly used; with yokes or collars spaced 2 ft. apart the lighter plank is amply strong and reduces the weight of the units to be handled as well as the amount of form lumber required. The thicknesses given apply to forms built with plank run vertically.

Fabrication of Column Form Units.—Column forms should be made in units which can readily be assembled, taken apart, and reassembled; batten boards being nailed to the planks or lagging to secure them together. The number, arrangement and size of the units are

determined by the shape and size of the column and the means adopted for handling the forms. In some cases the units are made up of narrow strips. This is to facilitate the reduction in size of the columns from floor to floor. Each of the narrow strips represents the reduction in diameter of the column from one story to the next. For square or rectangular columns there will be usually four units of lagging, one for each side, plus the number of yokes or collars used to bind the sides together. Forms for polygonal columns are difficult to construct in convenient units.

Frames for Column Form Units.—For columns it is customary to make a form or unit for each side and place around the trough thus formed horizontal frames of 2x4-in. or 4x4-in. stuff at intervals decided upon by the pressure to be resisted. Two-by-four-inch pieces are generally used for the frames. These frames (sometimes called bands, collars, stays, ties or yokes) are of several types, of which the following are in common use:

(1) *Timber frames* which consist of four strips, one on each side of the column. These are held together by means of blocks or lugs and hardwood wedges. On one side the piece may be loose, so that the same frame can be used for a narrower column by changing the position of the blocks or lugs. Sometimes these frames are nailed where they cross at the corners, instead of having blocks and wedges.

(2) *Bolted frames* which consist of two strips on opposite sides of the column form. These are tied together by bolts (usually about ⅝ in. in diameter). The space back of the bolt is generally blocked up and wedged. The strips or ties exert pressure on opposite sides of the form, while the other two sides are secured by hardwood wedges between the bolts and the form. These are placed as close as possible to the ends of the bolts. Sometimes the strips or ties of the column forms are reversed, so that the sides upon which the strips occur alternate. In this way the forms are stronger than when constructed with the strips or wooden ties all on one side. Washers should be used on all bolt-heads and nuts.

(3) *Clamped frames,* in which wrought iron clamps are used to hold the form together (see page 208).

It will be thus seen that column forms may be framed or yoked with slotted scantling or bolts, or with scantling boards, or with scantlings cleated and wedged or nailed at the corners. In other words, the frames are secured in various ways, by blocks and wedges, by bolts running through the ends of the pieces, by clamps, staples, etc. The four sides of the column form are sometimes tied at intervals by 1x6-in. cross-pieces or frames nailed where they cross at the corners. Such ties as these are not of great strength, and consequently they must be placed at close intervals, not farther apart than 2 ft. 6 in. for columns of ordinary height.

Spacing of Frames, Yokes, Stays, Etc.—Frames must be placed around the sides of the column form at intervals determined by the pressure to be resisted. They must be closer together at the bottom than at the top, due to the hydrostatic pressure of the wet concrete tending to burst the forms. This is especially true when the column

height is 18 or 20 ft., as the hydrostatic pressure of wet concrete becomes very great in a high column and is liable to burst the forms and let the concrete out, causing considerable loss of time and material. There is a common fault among contractors to skimp on the number of frames or yokes. Frames must be close enough together so as to allow no bulging between them. They are seldom spaced over 3 ft. apart unless very heavy lagging is used; 2-ft. spacing for frames or yokes is common. They are generally spaced 18 in. apart near the bottom of the column form, the intervals increasing to 24 in. near the top.

Opening at Bottom of Column Forms.—An opening should be left at the bottom of all column forms so that the column reinforcement can be adjusted and connected up and so that a clear view can be had through the form to detect any object that may have fallen into the form and become wedged; this same opening makes it possible to clean the form. In other words, loose hand-hole caps or small removal panels should be provided at the base of all column forms sufficiently large to gain access to the inside of the form to adjust the column bars and remove sawdust, shavings, chips and other materials that collect in the columns. These should be cleaned out just before concreting (see Art. 24, page 285). The inspector should not allow this opening to be closed until all is in readiness for pouring the columns.

Joints or Cracks in Column Forms.—All joints or cracks must be fairly tight, so as to prevent leakage of the liquid mass, which would leave the concrete porous or honeycombed. For methods of stopping joints in forms, see page 204.

Beveled Strips.—All square column forms should have diagonal or bevel strips in the corners unless the corners of columns are protected by metal strips; otherwise they are liable to be chipped off. It is also difficult so to tamp the concrete as to make the corners perfect. In this connection, see page 210. The bevel strips should run the full length of column forms and should be nailed on to two opposite sides of the forms when they are made up.

Octagonal Column Forms.—For octagonal columns a very simple bracing is obtained by beveling the eight sides of the column so as to fit together, bracing or squaring them by means of a wooden cross inside, removable as the concrete progresses, and tied together every 2 or 3 ft. vertically on the inside by means of No. 16 or No. 18 annealed wire, which is loosely wrapped a couple of times around the circumference. A $\frac{7}{8}$-in. scantling may be inserted underneath the wire and twisted sidewise so as to tighten the wire, after which a couple of nails should be driven through the $\frac{7}{8}$-in. scantling into the side of the octagonal form.

Circular Column Forms.—Architectural plans very frequently call for columns in reinforced concrete buildings to be cylindrical in shape instead of square, with bevel corners as mentioned above. Forms for these columns can be either of wood or of sheet metal.

There are several ways by which circular columns may be constructed of wood. Sometimes the forms are built up in *half-sections,*

the centering for the staves being constructed of $1\frac{1}{2}$-in. stuff, shaped to suit the radius of the column, or with straight faces, run vertically, and held together by flat ties. The two halves of the column form are held together either by means of wrought iron flat bands wrapped around the column form and properly secured with nails, or by means of heavy frames or yokes of wood to fit the outside of the narrow boards or staves; that is, with wood collars bolted together. Forms for cylindrical columns are sometimes made up in *quarter-sections,* and the forms to which the staves are nailed are sufficiently heavy to form the yoke or collar. These yokes or collars are made of about 3-in. stuff and are checked out at the corners so that they can be bolted together. They are spaced about as for rectangular columns (see page 215).

The two methods of form construction for circular columns just described are those usually employed, but the disadvantage consists in the fact that they leave the column marked with the joinings of the staves (to less extent, however, if the staves have been shaped to suit the radius of the column). While this offers no objection where the concrete work is to be plastered, and, in fact, is not really objectionable where the concrete work is exposed, yet in order to get very smooth columns sheet metal forms are sometimes used for molding when the columns are to be circular in form. Wood forms are rather clumsy affairs and are expensive to construct. Metal forms can be used to good advantage for circular columns, and are by odds the best for general work.

Metal forms for circular columns should be made in halves or quarters of No. 16 or No. 18 galvanized sheet iron, with angles along the edges for securing the several sections together. These forms are more economical than wood, especially where considerable use can be made of them; for example, when the columns are all of one diameter and there are a number of them.

In several instances where hooped or spiral reinforcement has been used the hooping has been wrapped with, or made of, expanded metal or other meshwork, and the concrete deposited inside the cylinder thus formed, without other form work. A moderately dry concrete (see page 186) is essential for such construction.

Ornamental Column Forms.—Forms for ornamental columns call for special design and construction. For many purposes, such as porch and portico work, the best plan is to mold the columns separately and erect them as stone columns of like character are erected. Metal forms may be used. (See Art. 54, page 507.)

Spacing and Squaring Column Forms.—All column forms should be accurately spaced in all directions and should be set square with the lines laid down on the plans. Great care must be taken in starting the erection of a new set of forms to keep the form spacing perfect and centered over construction below. Figures 14, 15 and 16 indicate the kind of errors in spacing and squaring that should be carefully watched for by the inspector.

Bracing Column Forms.—In putting up the column forms it is always well to brace them in two directions by diagonal braces or

stiff legs nailed to the forms and secured to piles of material or to the floor construction.

Light steel forms for circular columns must be supplemented by staging to hold them in line and to carry the ends of the girder forms that are ordinarily carried by the column forms. Four uprights arranged around the column so as to come under the connecting girders are commonly used. These uprights should be set close enough to the column to hold the form plumb by means of blocks or wedges.

Alignment of Column Forms.—Column forms must be plumb and set true to line and without winds or twists. Rigid care must be exercised in seeing that all column forms are plumb and true and are thoroughly braced to keep them so. (See page 211.)

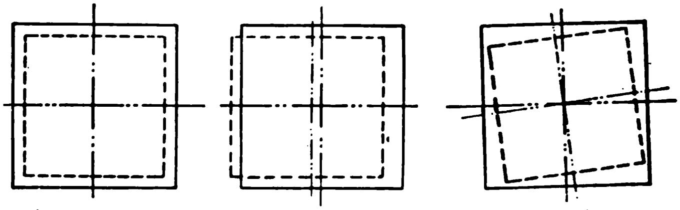

Fig. 14. Correct. Fig. 15. Incorrect. Fig. 16. Correct.
Spacing and Squaring Column Forms.

Supply of Column Forms.—In warm weather there is no need of having more column forms than one complete set for one story. (See page 213.)

BEAM AND SLAB FORMS AND SHORES

Slab and girder construction for floors and roofs is of four kinds: (1) Concrete slab and steel beam construction in place; (2) concrete slab and girder construction in place; (3) concrete joist and hollow tile construction in place (resting on concrete or steel beam); and (4) separately molded slab and beam construction. The fourth method of construction is distinct from the others in respect to form work as well as other details, and will not be considered in this article.

The construction of forms for concrete slab and girder floors should be such that the slab centers and the sides of the girder (or beam) molds can be removed without disturbing the bottoms of the girder molds. This insures the safety of the structure, for while the concrete may have been assumed as having sufficient strength for the slabs to carry their own weight, it is advisable to leave the uprights or shores under the main construction (beams or girders) for a period of a week longer, at least, to entirely avoid any danger of a collapse. This also at the same time releases the greater part of the form work for use again. It is of advantage also to lay bare the concrete as soon as possible to the hardening action of the free air. The slabs may be similarly supported by uprights or shores wedged up against plank caps; no very great amount of lumber is required for this staging and it gives a large assurance of safety.

The common method of constructing forms is to build up a falsework with individual planks cleated together for the sides of beams and girders, as well as separate boards for the lagging for the slabs, where the construction consists of girders, beams and slabs. These may be made to fit an entire panel if it is not too large for convenience of handling, for in all form work this feature is one which has to be considered. The ease with which such forms can be taken down and carried to another floor and reset is one of the determining factors of their use, aside from the fact of there being a number of stories of similar design and size.

Where concrete floors rest on structural steel, or where structural steel is erected first, as a skeleton, and the members so located as to form the tension part of the reinforced concrete construction, the forms should be supported on the temporary steel beams and girders so as to give them a certain stress during the placing of the concrete, which otherwise would act as an initial stress in the steel if the falsework were supported from below. In other words, if the reinforced concrete rests on structural steel or part of the reinforcement consists of structural steel, the forms should be suspended from said steel, so that the latter may obtain its deflection or initial stresses due to the dead loads while the concrete is setting.

Thickness of Lumber for Floor Forms.—For sides of beams or girders, either 1-in. or 1½-in. lumber is sufficient; usually a cheap grade of wood is used, such as sap pine. The bottoms of beams and girders should be of 2-in. stuff, although 1½-in. stuff is often used.

The lagging of slabs should be 1½-in. stuff, but it can be as light as 1 in. if the boards are narrow, say not over 6 in. wide, and tongued and grooved together. In fact, for floor panels 1-in. boards are most common, although if the building is eight or more stories in height 1-in. stuff, of soft wood, is likely to be pretty well worn out before the top of the building is reached, and the under surface of the concrete will show the wear badly. All lumber should be planed on the side next to the concrete; this permits the forms to be removed much more easily. The form boards for slab construction are very often made of tongue-and-grooved material of 4/4 or 5/4 dressed yellow pine flooring surfaced on one side.

Props or shores for slab and beam forms are usually of 4x4-in. material.

Fabrication of Beam and Girder Boxes or Forms.—Inverted boxes with the sides made with a draw form a common method of constructing this type of forms. The sides of beams and girders can be made up of two planks or whatever number is required to make the depth, and these be battened or cleated together so that each side can be handled as one piece. Where the beam is only 12 in. in depth it is customary to use a single board on the side, but where the beams or girders are 16 or 18 in. in depth, then two or more boards running lengthwise of the construction are employed. These are cleated together, being cut to length, the cleats being nailed on before the sides of the forms are put in place. These cleats act as a support for the joists which support form boards of the slab; or

strips may be nailed along the cleats or battens to support the joists. Cleats are usually spaced from 18 to 24 in. on centers on beams and girders, sometimes every other one projecting about 4 in. below bottoms to nail on cross-piece. Joists are placed at each cleat to brace sides of beams and girders. Where the beam forms intersect with the girder forms the sides of the forms of the girders are cut out, and this cut-out is reinforced with cleats on the side and on the bottom, to act as stiffeners and to support the beam form. When the floor slabs and their supporting girders are built monolithic, a 2x4-in. strip is very often nailed along the outside of the beam forms to carry the flooring for the slabs.

The sides of beam and girder forms should be splayed slightly, in order that they may be readily removed. If the forms are not made with the sides on a splay it will be difficult to drop them, as the concrete is very likely to adhere to the beam or girder box so as to make the task of removing the forms as a unit almost an impossibility; hence, if the design of the beams and girders shows these members with plumb sides, a slight deviation from the design would be necessary with this type of forms.

The side of the forms should project down past the edges of the bottom of the beam and girder forms, to permit the bottom to remain in place while the boxes are being removed.

The sides of beam and girder forms should be held tightly together by wedges, clamps or stiff braces, to prevent the pressure of the concrete springing them away from the bottom boards. Wrought iron clamps are frequently used in place of extra nailing on the bottom edge of beam and girder forms.

All beam and girder boxes should be true and rigid, and temporarily braced to stand handling and erection. They should have tight joints (see page 204). The sides of the beam and girder forms, when these members are to be deep, are sometimes so poorly braced and constructed as to bulge or warp. In fact, beams and girders are frequently badly twisted and sagged, because the forms are so poorly constructed that they cannot properly bear the weight of the concrete, thus spoiling the appearance of the floor system. While such carelessness may not produce an unsafe building, it is usually a criterion of the remainder of the work.

Openings in Girder Forms.—A pocket or loose hand-hole cap should be left in the bottom of all girders in a way to permit of the cleaning out of chips, shavings, etc., after the columns are poured. It is the care exercised in just such points that results in securing work which is first class in every respect, for it must be remembered that concrete once cast cannot be repaired without taking out an entire member or section of a floor, so that it becomes a very serious matter. Attention to details will obviate the necessity for such a procedure.

Diagonal or Bevel Strips.—All beam and girder forms should have diagonal or bevel strips in the corners. Triangular strips should be tacked along the corners of the forms as a fillet to cut off the

corner by a plane making equal angles with the adjacent faces. Chamfers should occur not only on the bottom edge of all beams and girders, but also in the ceiling angles, to prevent spalling off of the corners when removing forms, as the custom of using small crowbars to force the forms off the concrete is likely to break off corners. In this connection, see page 210.

Camber of Beam Forms.—When a load is placed upon any structural material like a beam, the stresses cause it to bend or deflect a little. In forms there is a slight movement due to the adjustment of the wedges under load and the compressing of the lumber, so that it is advisable to raise the beam forms slightly higher in the center than at the ends. It is well also to give the girder forms a camber or to crown them to allow for settling of the falsework. A rough rule for this is to assume a deflection of the forms and of the finished concrete beam or girder equal to about 3/8 in. for every 10 ft. of span, in order to provide for settlement under load. The bottoms of all beam and girder forms should tape off uniformly to each end, and they should be rigidly to this line. The bottoms of beam and girder forms are cambered so that any sag in the form will not give the appearance of sag to the beam or girder. In other words, as the forms will have more or less of a sag after being filled with concrete, it is customary to give them a slight camber so as to make them absolutely horizontal when the concrete is hardened.

Erection of Beam and Girder Forms.—Beam or girder boxes must frame into column boxes, and care must be taken to see that the joints at the connections are especially tight, as there must be no leakage of the concrete at or near the ends of beam or girder spans, as the shearing stress is greatest at the ends of spans. All joints throughout beam and girder boxes must be fairly tight, so as to prevent leakage of the liquid mass, which would leave the concrete porous or honeycombed. (See page 204.)

In some instances steel beams act as girders for the support of concrete beams, and the forms must be hung to these beams; in such cases long bolts or rods can be hung over the steel beams and extend below the bottom flange sufficiently far to permit of a heavy stringer running parallel to the steel beams to be secured thereto, and act as a secondary beam or support for the forms of the concrete beams. Whatever method is employed, all parts should figure strong enough to carry loads coming upon them, the same as if they formed a permanent construction.

Fabrication of Slab Forms.—The centerings for the slab panels are usually put up in sections and cleated or battened together, and where the reinforced concrete work is properly designed the panels between the beams are of uniform size, so that these battened form boards may be used in the construction of several floors. Forms for floor slabs should be made in units, say two or four pieces to a panel, or more, if the panels are large enough to warrant them. A very good system to employ in constructing forms is to have the lagging for slabs made up of 1x6-in. tongue-and-grooved boards bat-

tened on the under side, forming panels made in sections that can be readily handled without taking apart.

All slab forms should be well braced to prevent any sagging. If 1-in. form boards are used they should be supported on joists spaced not more than 2 ft. apart. Joists are usually supported on 2x4-in. strips fastened to the sides of the beam forms, or may be independently supported. They should be held up with a line of supports down the center line of panel. Where joists abut on beam forms, wedges should be used, being properly keyed in place. Tight fitting except by the use of wedges should not be resorted to. No spliced joists should be allowed at any point. Joists may be of 3x4 or 2x6-in. stuff. Sometimes 2x4 or 2x8-in. stuff is used, depending upon the span, spacing and weight of slab.

All slab forms should be true, level and out of wind.

Centering for Hollow Tile Floors.—Hollow tile and joist construction consists of a number of reinforced concrete beams separated by spaces into which the tiles fit. The construction of the forms is a very simple matter, as there is very little boxing. The common form of centering consists of planks, a little wider than the concrete beams, set where the beams are to come above. The tiles are placed in rows (3 to 5 in. apart), with their side edges resting on the planks, and form the sides of the concrete beam molds, a 1 to 3-in. slab being laid on top, connecting the beams laterally. An important feature of this type of construction consists in providing proper support of the flat lagging by means of shores or props.

Centering for Floor Slabs between Steel Beams.—The construction of centers for slabs and arches used as a floor filling between steel beams is a comparatively simple process. The centers usually consist of flat or curved lagging carried on straight or arched joists suspended from the steel beams or girders. In other words, centers for floor slabs between steel I-beams are made by suspending joists from the beam flanges and covering them with lagging. Frequently the joists and lagging are framed together into panels of convenient size for carrying and erecting. The construction is a simple one in either case where slabs without haunches or plain arches form the filling between beams. When the floor slab rests upon the top flanges of the beams the lagging joists may rest upon the bottom flange of the beams. A more complex centering is required where the slab has to be haunched around the I-beam. When the filling slab consists of either a flat floor plate or floor arch and rests upon the bottom flange of the beams the lagging is sometimes hung from the bottom flanges by hook bolts. When hook bolts are used to support forms from bottom flange of beams and the bottom flange of beam is protected by a layer of concrete, the hook bolts should be sawed off flush with the face of concrete.

Wire ties are sometimes used to support the lagging, being attached to the beams through holes punched in the top flanges, and pass around and support scantling, which in turn supports the lagging. Holes when bored in the slab forms should be at least 1/8 in. larger than the wires, in order to take down forms without injuring them.

Support of Floor Forms.—Floor forms are usually supported at the ends by wall and column forms and at intermediate points by shores (sometimes called posts, props, shoring, staging, studding, studs, supports, uprights, and vertical pieces) resting upon the floor below. In other words, girder and floor supports usually consist of uprights set under the girder form at intervals and occasionally under floor slab forms. These uprights rest on double wedges on the floor and bear with their upper ends against the bottom of the beam and girder forms; that is, they should bear against a cap piece and on a sill to distribute the load. They should be used freely and should we wedged up tight at bottom and top. Shores should be set up and do their duty without hard driving, which is sure to injure the setting concrete under them.

The inspector should observe that the supports of floor forms are sufficiently strong to carry the dead load of the wet concrete (see page 202). Many failures have been caused by weakness of the supports for concrete centering. Additional shoring must be provided when necessary to prevent sagging of forms when receiving concrete. All especially heavy construction should have the supports beneath it doubled, and all trussed work for the support of concrete should be submitted to the approval of the engineer before being used.

The inspector should also observe that the floor forms are so placed and so supported from the ground where the uprights rest upon the earth as to prevent warping, twisting or sagging. When the uprights supporting the first tier or story rest on the ground it is a very difficult matter to maintain a strictly level floor, due to the shores sinking in the ground when softened by rains, or in cases where the ground is of a yielding nature; in such case it is best to truss from shores set on the column footings, and run jack trusses from these to support the forms above, thus avoiding any settlement of the forms due to improper foundations. Trusses should also be used where it is desired to hasten the laying of the finished floor, especially the ground floor for the trenches can be dug for pipes, etc., without having to wait several weeks to remove the shores which would be in the way of the work.

While it is generally customary to support beam and girder forms by shores or vertical studs, sometimes to save material, and at the same time in order to brace the studding, the supports for the forms are differently arranged. Instead of using a number of shores or supports to the length of each beam or girder, only two are used and the intermediate supports are obtained by cutting in oblique braces on each side of the upright. Where the supports are arranged in this manner the vertical pieec is generally made of about a 4x6-in. piece, while 4x4-in. or 2x6-in. pieces are used for the braces. The braces are cut to the proper bevel to fit the under side of the bottom form board, and at the lower end to fit against the vertical. They are wedged to the vertical against a cleat or batten and nailed in order to prevent any possibility of their slipping. The upper ends of the oblique braces are securely wedged in place so as to bring an initial weight upon them, and are then secured from slipping by cleats or

battens and further wedging. There is a decided advantage in this method of stud centering, and that is that the oblique braces stiffen the story construction laterally and prevent any dangerous vibration or swaying when the fresh concrete is in place.

Bracing of Floor Forms.—All floor forms must be securely braced to preserve their alignment. Bracing is frequently done carelessly, and must be watched, particularly in regard to its sufficiency to preserve accurate alignment. Where it is possible, several shores should be connected by nailing diagonal and horizontal boards to the shores, thereby lining and bracing them with a stable falsework. All shores under forms should be braced at right angles in both directions, once in the height if the story is not exceedingly high, with, say, 1x6-in. ledger boards set about 6 ft. from the floor, to give headroom to workmen on the floor; ledger boards should also be run at the top of the struts in one direction at right angles to the beam forms and the sides of the beams wedged upon them. In other words, the shores or uprights should be stayed along the line of the joist at the top and longitudinally and transversely about midway for stories not exceeding 12 ft. in height. This prevents accidental dislodgment and swaying of the building.

All forms must be securely braced to withstand the loads that come upon them. The effect of the wind on exposed structures under erection should be carefully provided for as well. Little attention is paid to this danger, as a rule, but with works carried on in exposed localities subjected to considerable pressure, at times it is a menace that is well guarded against by providing sufficient diagonal bracing between the columns and shores as well as between beams, to prevent any dangerous vibration or swaying when the fresh concrete is in place. All studding must be well cross-braced, especially in the upper stories, to resist wind pressure.

A feature that should receive more attention is providing an adequately stiff or rigid sway-bracing for the centering. In discharging the contents from a wheelbarrow (some 200 lbs.) into a girder or narrow column there are often produced jars and lateral movements which may affect very materially freshly placed concrete in adjoining panels. In all cases care must be taken to secure falsework of sufficient stiffness. The inspector should carefully observe that the forms do not shake or vibrate, as any motion destroys the proper set of the concrete (see page 212). He should be very particular to see, before any concrete is poured (see Art. 24), that all forms are secured. Braces must be firmly fixed at the foot and top and must be stiff.

Location and Spacing of Shores.—Shores or props must not be located haphazardly. They should come at mid-span, one-third-span, quarter-span, etc., points. In other words, they should be placed at such frequent intervals that no material deflection can exist between supports in the beam and girder forms. Should the beams be over 8 ft. apart it may be necessary to introduce shores under the lagging or forms of the slab, unless the shores under the beams are made

extra heavy and the cross-beams under the lagging designed for the extra long span. Too much stress cannot be placed upon the importance of having an ample number of shores under the forms to hold them rigid and secure while the concrete is being placed, and to be so placed as to prevent sagging of the beams and girders before the concrete has hardened; many unsightly pieces of work have been performed due to lack of proper regard for this essential. Shores in each story must be located over the shores in the story below.

The spacing of shores or props will be regulated by the judgment of the foreman and boss carpenter; no general rule is applicable, except that enough lumber must be used to hold the forms rigid and true to line and level. Usually 3x4 or 4x4-in. pieces are set under centers of beams and girders varying from 3 to 5 ft. apart, according to the spacing of the beams and weight of the concrete to be put in the forms. As a rule, the shores should be placed under the floor forms at centers not farther apart than 4 ft.

Length of Shores.—Shores should be cut to proper length for the work, the length being such that the cap and footing pieces can be placed and the double wedges can be started and tightened. If the shores are cut too short, excessive blocking-up is necessitated and the support is liable to be unstable; if too long, they have to be hard driven into place, with danger to the form work.

Splicing of Shores.—It is the practice, in supporting slab and beam forms, where studding or shoring is used on different floors and the stories vary in height, to piece out the studding by nailing strips or cleats on the sides. Although such practice is probably necessary in some cases to secure economy, it is not recommended, because it is difficult to get a good square bearing where the two pieces of the studding abut, and quite frequently the supports of floor forms are dangerous from the fact that the ends of the studding and the piece used to make the extension do not bear squarely and are held from failure by the cleats nailed on the sides. The weight of wet concrete is considerable, and if the ends of the studs or shores bear only on an edge there is a tendency for them to buckle, or give, and unless the splice pieces on the sides are long and securely nailed such supports are an element of weakness and are liable to cause a serious collapse. Particular attention must therefore be paid to the piecing out of the shores supporting the slab and beam forms when they are used in the construction of the upper floors of an exposed building, as a combination of circumstances, such as a heavy wind storm, with the wet concrete just placed, might cause a failure of the supports, resulting in a bad collapse with its accompanying loss of property if not of life.

If the shores or studs have to be spliced, pieces of 1-in. material equal to the width of the shore should be placed on all sides. In other words, when an extension of this kind is made to the studding there should be cleats nailed on all four sides, though it is usual to find that one of these cleats has been left off. It is well to brace these splices against possible failure with ledger boards or braces.

That is to say, where numerous shores have to be spliced they should be well braced with cross-bracing and ledger boards.

Square Ends on Shores.—The ends of all shores should be sawed off square so as to have uniform bearing on wedges.

Wedges.—All shores should rest on wedges, driven in pairs to an even bearing. In fact, wedges should invariably be used to obtain the correct adjustment of shores, and should be loosened and removed without producing undue strains in the floor system. Wedges should preferably be on the floor at the bottom of the uprights or shores, where they will be accessible when adjustments are necessary. After leveling up forms the wedges should be nailed, so that there will be no slipping, or the wedges may be made sharp and thin enough to stick without being tacked. All wedges should be so constructed that the outside surfaces of any two wedges will be parallel and cut from 2x4-in. scantling. Wedges are most convenient in tightening up falsework and removing it again, afterwards, without shock or vibration.

Footings for Shores.—If the concrete floor is comparatively green, or the ground is soft, or a tile floor is used, the load from the floor above must be distributed by means of blocking, preferably of hardwood. If this is not done the supports or shores are sure to be pushed into the green concrete, into the ground, or to break the tile, causing a sag and possible cracks in beams and floor slabs. No shoring should be erected over soft ground or concrete less than a week old (never over tile floors) without a footing block of ample size to properly distribute the load.

Form work for a reinforced concrete floor is so carelessly constructed at times that the ends of the shores or props rest on soft earth in such a manner as to allow the beams and girders to sag under the weight of the wet concrete. The concrete sets with this sag in the beam and girder members, and the entire floor system looks as if it were greatly deflected. If shores or other supports for reinforced concrete work must rest upon the soil, they should have placed beneath them, over good soil, a 3x10-in. plank at least 3 ft. long. Where the soil is soft, several planks should be crossed, in order to get sufficient support to prevent settling under the weight of the concrete.

Caps for Shores.—The shores should be properly capped with plank or scantling to distribute the pressure, especially where the shores are used to support floor slabs or beams after the forms have been removed.

Covering Slab Forms with Paper.—Forms under floor slabs are sometimes covered with resin-sized sheathing paper lapped 1 in. at joints and tacked in place, but its use needs constant attention in order to secure satisfactory results. It is somewhat difficult to keep the paper absolutely smooth so that the final surface does not show wrinkles. Unless the paper is very oily it will adhere to the concrete, necessitating that it be burned off so as to effect its removal, as a thorough soaking very seldom removes the paper entirely. (See pages 204 and 234.)

WALL FORMS

The construction of forms for walls, while not involving the complex carpenter work demanded by floors with beams and girders (see page 218), does require great care in providing sufficient bracing to maintain the forms plumb and true to line.

Lumber for Wall Forms.—For ordinary walls $1\frac{1}{2}$-in. lumber is good, although for heavy construction, where derricks are used, 2-in. stuff is preferable; while for small panels 1-in. boards are lighter and easier to handle. One-and-one-half-inch stuff is usually used for walls, with 3x4 or 3x6-in. vertical upright on each side, spaced not over 3 ft. centers. Under no conditions should exterior walls be cast in molds made of varying thickness, regardless of what finish is adopted. Even if plastered $\frac{3}{4}$ in. thick, it will always show a difference in color when the finished surface dries out.

The forms for all walls should be of lumber planed on one side and double-edged. One edge should be slightly beveled. This beveled edge may be placed against the straight edge of the next plank and driven to form a tight joint with an even surface. (See page 205.)

Fabrication and Erection of Wall Forms.—For structures having large areas of flat surfaces, such as a retaining wall, the forms are sometimes made in panels or sections, which, after the concrete has set, may be taken down in one piece and be set up again, thus facilitating the placing and the removal of the forms. All wall forms should preferably be made and erected in sections or units, for convenience in handling and removal without injury to the completed work. In building construction, movable forms are commonly employed for walls more than one story high, and should always be employed above one story, to save staging timber. A good method of constructing the forms is to make large panels of tongue-and-grooved boards, as mentioned for slabs, on page 221. They are fastened together with battens or cleats, and placed one above the other or end to end, as may be required, being held lightly nailed to the upright posts. The panels can be used over and over again if the wall is solid and extensive.

Forms for thin reinforced walls are generally made to be supported by the concrete already in place. The bottom board in wall forms should be placed last, where practicable, so as to permit cleaning the forms (see Art. 18). Wall ties, either bolts, wire or steel, should be put through at right angles, or square with the wall, otherwise the forms will be "skewed"; it should be of an approved design, such that no ironwork is left exposed on completion of the wall. All forms should be studded carefully to avoid bending of boards between studs.

Great care should be taken in handling panel or sectional forms for walls, so as not to batter the edges. If they are battered, or if planks are warped so as to open up a joint, it may be filled or made straight by means of a strip of wood, oakum or putty (see page 204).

Interior Support of Wall Forms.—Some device must be provided to prevent the forms from bulging and at the same time keep them

the proper distance apart. Forms when used on both sides of a narrow wall can be held together by bolts, wires or special devices. In other words, the uprights should be prevented from spreading by means of bolts running through the walls, or, as is sometimes the case, by No. 10 wire loops extended around the uprights on both sides of the wall and twisted within the body of the wall to hold the forms tight up against spreaders or struts placed between the forms. Wooden struts or concrete struts may be used for supporting wall forms from the interior while filling, being so spaced as to prevent distortion. The struts or spacers should always be placed where the sheathing is supported by a stud, and the wire should loop the stud or upright; then by twisting the wire with a short bar or piece of wood the forms can be drawn and held rigidly in place during filling. When the concrete has been placed to the level of the strut or spreader, it can be removed and the weight of the concrete will hold the forms apart. Wooden struts must be removed when the concrete fills the forms where they occur. Concrete struts may be left in if so desired. On removal of the forms the wires should be cut close to the concrete, the edges stove in with a punch, and the surface smoothed over.

Exterior Bracing of Wall Forms.—The forms, in addition to the interior bracing, should be braced on the outside. The upright studs should be braced horizontally by running a horizontal stringer piece the full length of the wall and bracing it to some substantial support to keep the wall in line. For wall forms, inclined props or braces reaching from the ground to studding are used for bracing walls of moderate height, such as retaining walls, wing walls, and abutments. For building walls of some height a gallows frame arrangement or the common braced staging used by masons and carpenters is used.

Forms for foundations, retaining walls, and ordinary construction are usually braced to the earth, the diagonal braces being held in position by posts driven into the ground. Care must be taken to see that forms are properly braced, as the exterior bracing must be relied on for holding the forms to alignment. Failures of such forms are frequently caused by the giving way of the posts due to the yielding of earth. Earth is a poor material to depend upon for holding forms rigid. The posts against which the ends of the diagonal rest should be driven deep. They should also be driven as nearly vertical as possible. The usual way is to drive them on a slant, but experience has shown that vertical posts are the stiffer, especially when the ground is poor. The top soil is seldom able to carry much of a load, hence the brace should be driven deep in order that it may obtain sufficient anchorage.

Care must be exercised to prevent forms from lifting during filling. In a wall section which has considerable batten, a hook made of reinforcing steel, embedded in the foundation, may be used to tie the forms, the tie being made with No. 8 wire. In trench work, where there is sufficient depth the upward or side movement of forms should be cared for by bracing to the sides of the trench.

Use of Wire Ties and Spacers.—All wire ties for wall forms should be in place and made taut so as to pull the sides close against the spacers. The wire should preferably pass twice through the forms, the ends twisted together, and any surplus cut off with nippers. The wire is then tightened by twisting the two strands together inside of the forms, a stick being employed for that purpose, as shown in Fig. 17. Before the wire is drawn up, a wooden spacer or spreader of length equal to the required width of the wall should be placed beside the wire, where it should be left until the concrete reaches that height. All spacers should be removed from the forms as soon as the concreting reaches them. The use of spreading strips

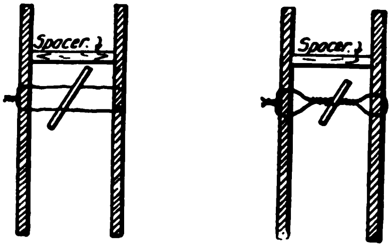

Fig. 17. Wire Tie for Forms.

unattached to the wire ties is probably the best and cheapest method of holding wall forms apart. The projecting ends of all wire ties used to hold together the sides of wall forms and left embedded in the concrete should be cut off deep enough to keep rust spots from showing on the face of the wall.

Small wire must not be used for tying wall forms where there will be much pressure of the wet concrete; the wire will cut into the wood and allow the forms to spread. No. 8 wire will generally fulfill the requirements of most work. Use bolts where there will be much strain on the forms.

Wire forms are much more secure than those which are merely braced. They possess, however, the following objectionable features:

(1) The ends of the wires are exposed when the forms have been removed.

(2) The wooden spacers or struts are often left in the concrete. Careless or lazy workmen will frequently simply knock them out and leave them embedded in the wall, or bury them as they stand.

(3) The wire gives a little as the concrete is tamped, causing the form to bulge. There is no practical way of taking up this give.

Bolt Ties and Spacers.—Bolts are better than wire for wall forms. They should be tightened against spacers set between the two sides of the forms inside. Wooden spacers can be removed as soon as the bolts are tightened, while the give can be taken up by tightening the nuts on the bolts. Bolts should preferably be enveloped inside the forms with sleeves, or thoroughly greased; otherwise the bolt will stick and can be drawn out only by wrenching and injuring the concrete.

Care should be taken to construct forms in such a way that tie-rods will not come closer than 4 in. to a projecting corner or other detail, or the concrete may be spalled off in pulling them. The author would suggest that bolts through forms should not be within 1 ft. of a finished concrete edge if possible to place them elsewhere. They are likely to break the concrete during their removal, especially if not absolutely straight.

Projecting Ends of Wire Wall Ties, Etc.—All projecting wires, bolts, or other devices used for securing wall forms, and that pass through the concrete, should be cut off at least one (1) inch beneath the finished surface and the ends covered with mortar. Care should be taken to see that there is not a lot of wire ends left on the face of the concrete, to ultimately rust and discolor it.

Removal of Tie-Rods.—When it is desired to withdraw bolts or rods used to support thin wall forms, they may be thoroughly greased or wrapped with stiff paper before the concrete is placed. Use a tin tube or piece of pipe through which to pass the bolt, or wrap it loosely in oiled paper, so as to make its removal more certain. The pipe, if used, will act as a spacer for the forms as well as a sleeve for the bolt. The sleeves may consist of pasteboard tubes. It will usually be found that these are just as efficient and much easier to place and trim than wrought-iron pipe.

The method of using oil or grease is objectionable where an impervious seal is required, as the oil placed on the bolts to permit of their removal prevents a water-tight bond between the mortar plug and the body of the wall. To avoid this difficulty a number of arrangements are in use where two short bolts are connected to wire loops in the body of the wall. The wire loops remain in the wall, so that the main portion is solid and impervious, while the shallow holes, left on each side when the bolts are removed, are filled with cement mortar to preserve its sightliness.

Tie-Rods Left in the Concrete.—When specified that tie-rods are to be left in the concrete wall, they may be provided with sleeve nuts near the end, which, when unscrewed, will leave the end of the rod within the wall not less than 2 in. from the face. The hole left by the nut should be carefully filled with 1:2 or 1:3 mortar after the forms are removed; or the holes may be filled with cement paste mixed with some waterproofing compound.

Concrete Wall Spacers or Struts.—When the space between forms is so narrow that the removal of struts becomes a troublesome task, concrete struts may be substituted. These struts are made in advance of being used and allowed to set hard. If the wall is not too high, the spacers or struts need not be closer than 3 ft. in each direction. When interior partitions of buildings are made of monolithic concrete, this method of keeping the forms apart is preferred to any other.

Concrete struts should be placed in the same manner as wooden and should be broken with a tamper when the concrete is placed to the proper level; or, if they have been cast with a water stop, they

may remain in the wall. Care must be taken to prevent a void immediately under the strut or a water channel along the side of the strut. Concrete struts generally present a bad appearance in the finished wall if allowed to remain. Where the appearance of the exterior surface on the wall is of no great importance, concrete spacers may be used, composed of the same quality of concrete as the rest of the wall.

A good form of spreader consists of a concrete block about 3x3 in. by thickness of the wall, with a longitudinal hole 1/8 in. larger than the bolt to be used. When the forms are removed the holes are filled on each side with cement mortar. The concrete strut may also be used as ordinary spreading strips, without having holes through them.

Tapered Wooden Spacers.—Tapered wooden spacers, bored to receive the bolt, may be used instead of concrete spacers, but should be well oiled and be driven out as soon as the forms are removed.

Alignment of Wall Forms.—The alignment of edges, corners and sides of walls should be carefully preserved by frequent tying and bracing of the forms and by the use of heavy stringers or rangers. Keep careful check on the alignment of movable panel forms used in wall construction; they require special skill and care to keep in line. Do not put any confidence in the ability of the average carpenter to carry walls vertically with a level. The building of plumb vertical walls can only be obtained when everybody on the work looks out for them. The author has seen some very excellent concrete work done in different parts of the country where many of the concrete walls were as much as 2 or 3 in. out of plumb. (See page 211.)

Foundation Walls.—Forms should be constructed for foundation walls in case the earth will not stand plumb in the excavation. Except in sand and gravel, no side pieces are required for footings, as all other soils will stand vertically for a depth of 8 to 12 in.; hence, all that is necessary is to dig the trench the exact width and depth required for the footings.

Sloped Wing Walls.—Where wing walls are called for which have slopes corresponding to the angle of repose of earth embankments, these slopes should be finished in straight lines and surfaces, the form for such wing walls and slopes being constructed with its top at the proper slope, so that the concrete on the slope may be finished in short sections, say, from 3 to 4 ft. in length, and bonded into the concrete of the horizontal sections before the same has become set, each short section of sloped surface being grooved with a cross-line separating it from the adjacent sections. The contractor should not be permitted to finish the top surface of such sloped walls by plastering fresh concrete upon the top concrete which has already set, but the finished work should be made each day as the horizontal layers are carried up, to accomplish which the form should be constructed complete at the outset; or, if the wing wall is very high, short sections of the form, including the form for the slopes, should be completed as the horizontal planking is put in place.

ARCH CENTERS

Substantial centers are necessary in the construction of concrete arches, as it is desirable to support the structure without any possibility of the lagging sinking or sagging when the concrete is being put in place or before it has set. The centers must remain as nearly as possible invariable in level and form from the time it is made ready for the concrete until it is removed from underneath the arch, and, when the time for removal comes, the construction must be such that the operation can be performed with ease and without shock or jar to the masonry. The problem of center construction is thus two-fold; one of building a structure which is immovable until movement is desired, and then moves at will.

The centering employed for a concrete arch is similar to that used for a masonry arch, except that in the former the lagging must be made smooth so as to give the exact shape to the concrete and so constructed that the concrete will not adhere to it. In other words, forms for concrete arch bridges resemble in many particulars those used in the construction of stone bridges. Not only must the arch ring be supported, but provision must be made to retain the concrete for the spandrel construction. The spandrel, together with face wall centering, may be built in place at the same time the arch ring concreting is put in place. The vertical timbers supporting the lagging may be tied together at the top by cross-ties (see page 208).

Classes of Centering.—Arch centering in general may be divided into two classes. In the first class, struts or braces support the timbers or ribs carrying the lagging at every joint. These struts or posts are braced together to form transverse bents, which are spaced at convenient distances apart along the axis of the arch and braced longitudinally. In other words, supports for the centers can be arranged in any way that judgment and economy dictate.

In the second form, trusses are employed. These trusses may carry the lagging directly, in which case they must conform to the curve of the intrados of the arch, or they may support short braces which in turn support the ribs. These trusses may be carried on bents or masonry supports at the ends. Centers of this class are often called cocket centers. There is no distinctive division between the two classes.

The type of centers to be used in any case will depend entirely upon local conditions. Where the restriction of the opening is of little or no importance, bents would probably be the most economical and satisfactory. In other cases, where it is desirable to obstruct the opening as little as possible, the trussed form of centering would probably be best adapted.

Rigidity of Arch Centers.—As in masonry construction, arch centers for concrete should be perfectly rigid so that the arch will not be stressed in the slightest degree before the concrete attains a perfect set. All centers must be made as strong and as rigid as possible, as any deformation of the center due to insufficient strength or improper bracing will cause a corresponding change in the intrados

of the arch, and consequently in the line of resistance, and may endanger the whole structure.

Cambering Arch Centers.—Since timber is not absolutely rigid, but is apt to settle, the rise of the centering should be made slightly greater than the rise designed for the arch, so that after deflection the arch may be of the desired curvature. In other words, the crowns of the centers should be raised above the intended height of the finished arch to allow for settling when the centers are being loaded and when struck. In important construction, where long-span trusses are used to carry the centering, it is sometimes necessary to determine the amount of probable deflection in the truss. This may be done by using the usual formula for deflection, which may be obtained from any work on mechanics. For most purposes where trussed centering is used a slight camber may be assumed equal in amount from 1/1000 to 1/500 of the span. Mr. Edwin Thacher provides for an additional rise in the centering of 1/800 of the span, while others assume from 1/1200 to 1/600 of the radius at the crown. Still others make an allowance for settlement equal to ¾ in. for each 30 ft. vertical height.

Arch Ribs or Center Frames.—The ribs upon which the lagging rests directly are usually made of planks spiked together so as to break joints, and cut to curve parallel to the intrados of the arch, but a sufficient distance below it so that the lagging, when applied, shall coincide with the intrados of the arch. Sometimes the ribs are steel shapes bent to the desired curvature. Two-inch plank sized to 1¾ in. is usually employed for lagging. Supporting ribs should not be spaced more than 3 to 4 ft. centers when such plank is used. While it is customary for these ribs to be covered with narrow planks (lagging) running parallel with the axis of the arch, sometimes transverse timbers spaced 1 ft. or more apart are placed on top of the ribs and a tight longitudinal floor of tongue-and-grooved flooring used to form the lagging.

For spans up to 40 ft. a braced wooden rib with one center support and two end supports is generally used, but for longer spans a trussed center with support 10 to 18 ft. apart is employed.

Bolting Centers.—In constructing centers for arches of more than 30-ft. span, no reliance should be placed upon spiking, but all main members should be bolted together at joints. In other words, no dependence should be placed in nails, except for fastening the lagging, for securing the wedges, and for minor details.

Lagging.—The lagging should be sized, dressed on the upper side, and laid with radial joints parallel to the arch axis. That is to say, lagging should be of even thickness and made smooth to give a good surface to the soffit of the arch. Two-inch plank sized to 1¾ in. is usually employed for lagging, the supporting ribs being from 3 to 4-ft. centers. The lagging for the center may be in two thicknesses, but the top layer should preferably be tongue-and-grooved lumber, and the lower layer should be dressed to match the top surface when in place. Lagging should have a deflection under the full load of the arch of not more than ⅛ in. With thin lagging care must be taken

to prevent deflection. The lagging is sometimes covered with building paper of a strong and durable character. In this connection, see pages 204 and 226.

Striking Arch Centers.—Suitable means must be provided for striking or lowering the center without injuring the surface of the concrete and without straining the arch. In order that the center may be struck, or lowered, uniformly and without shock, wedges or sand boxes are used under all of the supports. In other words, the centers may be provided with striking wedges or sand boxes so that the lowering of the center may be effected slowly. Jackscrews also may answer the same purpose as wedges or sand boxes. Centers in all cases must be dropped away from the arch readily.

Wedges.—The wedges usually consist of a pair of folding wedges (1 to 2 ft. long and 6 in. wide), preferably of hardwood, having a slight taper. It is necessary to remove the centers slowly, particularly for large arches; and hence the striking wedges should have a very slight taper of from 1 to 5 to 1 to 10. The taper should vary with the span of the arch, the longer the span, the less the taper. To lower the centers equally the wedges should be driven back uniformly (see page 254). To facilitate this, compound wedges are sometimes used. By driving the wedges all work resting on the wedge will be lowered uniformly.

All wedges should be so constructed that the outside surfaces of any two wedges will be parallel, and the pressure on the same should not exceed 300 lbs. per square inch. The grain of wedges should run with the slope, and their contact faces should be planed true and smooth for their entire width and length, and if required they should be lubricated to facilitate the striking of the centers without unnecessary jar and vibration. The wedges should be of straight grain oak only. (See also page 226.)

Sand Boxes.—Sand boxes usually consist of a steel cylinder in which sand is confined. A wooden plunger rests on the sand, and on these wooden plungers is carried the centering of the arch. Near the bottom of the cylinder is a plug, which may be withdrawn and replaced at pleasure, by means of which the outflow of the sand is regulated. In other words, the sand may be readily removed by letting it out through a hole in the cylinder or box, as the case may be. As the sand is allowed to escape, the centers will lower and the amount of this lowering can be easily controlled by the amount of sand allowed to escape.

If the contractor wishes to use sand boxes to lower the centers, he should be required to submit details of same for the approval of the engineer in charge of the work.

In using sand boxes particular care should be exercised, first, to secure a proper sand and, second, to exclude all foreign material from the boxes, which must also be properly sealed to prevent the entrance of foreign matter. Care should be taken to secure a good quality of sand to be used in the boxes. The sand should be thoroughly washed, to remove all silt, and thoroughly dried before using. In other words, the sand must be clean and of proper quality.

A poor quality of sand for use in sand boxes has caused trouble on several occasions.

Particular care must therefore be employed when sand boxes are used, for if any foreign substance is allowed to enter them, or they are not properly sealed, trouble may be experienced, either in their settling too soon or failure to settle at the proper time. Care must be taken to keep the sand dry during the entire construction of the arch and so that it will run when the boxes are tapped. Sand boxes should be waterproof. The sand in these boxes must be thoroughly packed to prevent settlement of the concrete before setting.

Where any of the above precautions are lacking, trouble is likely to be experienced either through the sand flowing prematurely or its failure to flow at the proper time.

Foundations.—Substantial foundations must be provided for the center, so that the supports for the form will be as unyielding as possible. If the subsoil is sufficiently firm, mud sills may be put down, and the bents or struts rested directly on them, but in poorer soil temporary masonry or pile foundations should be provided. Piles should be driven to a firm bearing, so that no settlement will occur when the weight of the structure is brought upon them. The foundation should preferably be of concrete and of such size as will not permit of a settlement greater than 3/16-in. under the maximum loads they are designed to carry.

Workmanship.—All carpentry work should be the best class of heavy timber work. Care should be taken to see that all saw cuts are true and surfaces of abutting timbers be adzed off to make a snug fit.

Adhesion of Concrete to Lagging.—Care should be taken to prevent the concrete from sticking to the lagging. The adhesion of the concrete to the lagging would mar the smoothness of the finish and might cause difficulty in striking the centers. This last item is of more serious consequence than a possible roughness in the cases where the bridge is to be given a pebble-dash (see page 414) or other rough finish. To prevent the concrete from adhering and to obtain a smooth surface, the lagging should be dressed smooth and any of the methods described in Art. 18, page 239, employed—i. e., wetting the lagging or soaping or oiling same. The lagging may be covered with cloth or paper. Sometimes a layer of clay is used in the place of the above mentioned substances. Where centering is to remain in place for a long period, however, it is found that there is very little likelihood that the concrete will adhere to the lagging.

Shimming Joints.—Just before the centering is loaded it should be inspected, and all joints which have been opened up should be shimmed tight, using shingles or thin wedges. During the construction of the arch similar wedging should be done, as the settlement of the falsework may open joints.

Forms for Sections of Arch Ring.—Suitable forms should be constructed to hold in place sections of arch rings being concreted. If the concreting is done in longitudinal sections, the forms should be set vertical and parallel with the face of the arch. If the con-

That is to say, where numerous shores have to be spliced they should be well braced with cross-bracing and ledger boards.

Square Ends on Shores.—The ends of all shores should be sawed off square so as to have uniform bearing on wedges.

Wedges.—All shores should rest on wedges, driven in pairs to an even bearing. In fact, wedges should invariably be used to obtain the correct adjustment of shores, and should be loosened and removed without producing undue strains in the floor system. Wedges should preferably be on the floor at the bottom of the uprights or shores, where they will be accessible when adjustments are necessary. After leveling up forms the wedges should be nailed, so that there will be no slipping, or the wedges may be made sharp and thin enough to stick without being tacked. All wedges should be so constructed that the outside surfaces of any two wedges will be parallel and cut from 2x4-in. scantling. Wedges are most convenient in tightening up falsework and removing it again, afterwards, without shock or vibration.

Footings for Shores.—If the concrete floor is comparatively green, or the ground is soft, or a tile floor is used, the load from the floor above must be distributed by means of blocking, preferably of hardwood. If this is not done the supports or shores are sure to be pushed into the green concrete, into the ground, or to break the tile, causing a sag and possible cracks in beams and floor slabs. No shoring should be erected over soft ground or concrete less than a week old (never over tile floors) without a footing block of ample size to properly distribute the load.

Form work for a reinforced concrete floor is so carelessly constructed at times that the ends of the shores or props rest on soft earth in such a manner as to allow the beams and girders to sag under the weight of the wet concrete. The concrete sets with this sag in the beam and girder members, and the entire floor system looks as if it were greatly deflected. If shores or other supports for reinforced concrete work must rest upon the soil, they should have placed beneath them, over good soil, a 3x10-in. plank at least 3 ft. long. Where the soil is soft, several planks should be crossed, in order to get sufficient support to prevent settling under the weight of the concrete.

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WALL FORMS

The construction of forms for walls, while not involving the complex carpenter work demanded by floors with beams and girders (see page 218), does require great care in providing sufficient bracing to maintain the forms plumb and true to line.

Lumber for Wall Forms.—For ordinary walls $1\frac{1}{2}$-in. lumber is good, although for heavy construction, where derricks are used, 2-in. stuff is preferable; while for small panels 1-in. boards are lighter and easier to handle. One-and-one-half-inch stuff is usually used for walls, with 3x4 or 3x6-in. vertical upright on each side, spaced not over 3 ft. centers. Under no conditions should exterior walls be cast in molds made of varying thickness, regardless of what finish is adopted. Even if plastered $\frac{3}{4}$ in. thick, it will always show a difference in color when the finished surface dries out.

The forms for all walls should be of lumber planed on one side and double-edged. One edge should be slightly beveled. This beveled edge may be placed against the straight edge of the next plank and driven to form a tight joint with an even surface. (See page 205.)

Fabrication and Erection of Wall Forms.—For structures having large areas of flat surfaces, such as a retaining wall, the forms are sometimes made in panels or sections, which, after the concrete has set, may be taken down in one piece and be set up again, thus facilitating the placing and the removal of the forms. All wall forms should preferably be made and erected in sections or units, for convenience in handling and removal without injury to the completed work. In building construction, movable forms are commonly employed for walls more than one story high, and should always be employed above one story, to save staging timber. A good method of constructing the forms is to make large panels of tongue-and-grooved boards, as mentioned for slabs, on page 221. They are fastened together with battens or cleats, and placed one above the other or end to end, as may be required, being held lightly nailed to the upright posts. The panels can be used over and over again if the wall is solid and extensive.

Forms for thin reinforced walls are generally made to be supported by the concrete already in place. The bottom board in wall forms should be placed last, where practicable, so as to permit cleaning the forms (see Art. 18). Wall ties, either bolts, wire or steel, should be put through at right angles, or square with the wall, otherwise the forms will be "skewed"; it should be of an approved design, such that no ironwork is left exposed on completion of the wall. All forms should be studded carefully to avoid bending of boards between studs.

Great care should be taken in handling panel or sectional forms for walls, so as not to batter the edges. If they are battered, or if planks are warped so as to open up a joint, it may be filled or made straight by means of a strip of wood, oakum or putty (see page 204).

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Footings for Shores.—If the concrete floor is comparatively green, or the ground is soft, or a tile floor is used, the load from the floor above must be distributed by means of blocking, preferably of hardwood. If this is not done the supports or shores are sure to be pushed into the green concrete, into the ground, or to break the tile, causing a sag and possible cracks in beams and floor slabs. No shoring should be erected over soft ground or concrete less than a week old (never over tile floors) without a footing block of ample size to properly distribute the load.

Form work for a reinforced concrete floor is so carelessly constructed at times that the ends of the shores or props rest on soft earth in such a manner as to allow the beams and girders to sag under the weight of the wet concrete. The concrete sets with this sag in the beam and girder members, and the entire floor system looks as if it were greatly deflected. If shores or other supports for reinforced concrete work must rest upon the soil, they should have placed beneath them, over good soil, a 3x10-in. plank at least 3 ft. long. Where the soil is soft, several planks should be crossed, in order to get sufficient support to prevent settling under the weight of the concrete.

Caps for Shores.—The shores should be properly capped with plank or scantling to distribute the pressure, especially where the shores are used to support floor slabs or beams after the forms have been removed.

Covering Slab Forms with Paper.—Forms under floor slabs are sometimes covered with resin-sized sheathing paper lapped 1 in. at joints and tacked in place, but its use needs constant attention in order to secure satisfactory results. It is somewhat difficult to keep the paper absolutely smooth so that the final surface does not show wrinkles. Unless the paper is very oily it will adhere to the concrete, necessitating that it be burned off so as to effect its removal, as a thorough soaking very seldom removes the paper entirely. (See pages 204 and 234.)

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The forms for all walls should be of lumber planed on one side and double-edged. One edge should be slightly beveled. This beveled edge may be placed against the straight edge of the next plank and driven to form a tight joint with an even surface. (See page 205.)

Fabrication and Erection of Wall Forms.—For structures having large areas of flat surfaces, such as a retaining wall, the forms are sometimes made in panels or sections, which, after the concrete has set, may be taken down in one piece and be set up again, thus facilitating the placing and the removal of the forms. All wall forms should preferably be made and erected in sections or units, for convenience in handling and removal without injury to the completed work. In building construction, movable forms are commonly employed for walls more than one story high, and should always be employed above one story, to save staging timber. A good method of constructing the forms is to make large panels of tongue-and-grooved boards, as mentioned for slabs, on page 221. They are fastened together with battens or cleats, and placed one above the other or end to end, as may be required, being held lightly nailed to the upright posts. The panels can be used over and over again if the wall is solid and extensive.

Forms for thin reinforced walls are generally made to be supported by the concrete already in place. The bottom board in wall forms should be placed last, where practicable, so as to permit cleaning the forms (see Art. 18). Wall ties, either bolts, wire or steel, should be put through at right angles, or square with the wall, otherwise the forms will be "skewed"; it should be of an approved design, such that no ironwork is left exposed on completion of the wall. All forms should be studded carefully to avoid bending of boards between studs.

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to the concrete and is hard to remove. The use of paper needs constant attention in order to secure satisfactory results (see page 204). It is somewhat difficult to keep the paper absolutely smooth, so that the final surface does not show wrinkles. Unless the paper is very oily it will adhere to the concrete, necessitating that it be burned off so as to effect its removal, as a thorough soaking very seldom removes the paper entirely. (See pages 226 and 234.)

Lining Forms with Canvas.—Edward Godfrey in his book on "Concrete," page 98, recommends that canvas painted with linseed oil be used as a cover for rough forms. It is waterproof and would therefore not absorb water from the concrete; it would also prevent the leakage of the liquid mortar that occurs at cracks or joints in the wooden forms (see page 204). It would probably be economical for the reason that it does not require planed boards in the forms and it could no doubt be used repeatedly. It would further help to keep the frost out of the concrete.

Art. 19.—Removal of Forms and Centering

Removing the centering before the concrete has had time to set properly is the cause of the greatest number of reinforced concrete building failures. In fact, premature removal of centering has been the cause of most of the deplorable accidents which have tended to retard the advancement of reinforced concrete in the United States, and which has caused investors to look askance at this type of construction, otherwise so desirable from an engineering and economical standpoint. The removal of the centering is frequently hurried because of the desire to use the centering material on another floor, or because the floor space is wanted by the other mechanics in finishing the building. Trying to gain time on each floor by "pulling" one day sooner because nothing happened to the floor below, is quasi-criminal; something will happen in such cases with the result that a scorce of men find themselves before a grand jury trying to explain what can be stated in three words, "Too much haste." Haste can be accomplished by order and system supplemented by proper mechanical appliances, but not by "pulling forms" too soon. Other causes have also contributed to reinforced concrete failures, such as improper design and bad workmanship. (See page 17.)

GENERAL REQUIREMENTS

Forms shall not be removed until the concrete shall have become hard enough to be unquestionably self-supporting. No forms should be allowed to be removed except in the presence of the inspector. The most important precaution in reinforced concrete construction, and whose importance cannot be overestimated, is *caution in the removal of the form work.*

Notification of Form Removal.—No forms whatever should be removed at any time from reinforced concrete work without first notifying the engineer in charge of the work. But such notification

should not be considered to relieve the contractor of responsibility for the construction and removal of such forms.

Contractor's Risk.—Forms are removed from the concrete at the contractor's risk at any time, and should any of the concrete give way by such removal or become permanently injured, the contractor should be required to remedy same at his own expense. The contractor should be expected by suitable observations to know when the concrete in any section of the work is sufficiently hardened to bear its own dead load plus additional load as may be imposed by the work of installation and should not be relieved of responsibility for premature removal of centers. The engineer, however, may when he deems advisable, order the centering to remain for a longer time. The engineer's acquiescence in permitting removal of forms should not by any means relieve the contractor of responsibility for same.

Time of Removing Forms.—In all cases the forms should be removed as soon as possible so that they can be used over again and so that the concrete may be exposed to the air to hasten hardening. However, under no circumstances should forms be removed until the concrete has attained sufficient strength to resist accidental thrusts and permanent strains which may come upon it. This is a matter of great importance, and lack of attention to this item has caused most of the disastrous accidents to reinforced concrete. The removal of the forms, therefore, calls for discrimination as to the proper time. In fact, good judgment and extreme care are essential in removing forms or centering. It is far better to be a few days behind time than to take chances on a too early removal of the forms. Much attention must be given to this portion of the work, which is fraught with danger under incompetent direction. Forms supporting reinforced members should be left in place until the concrete rings sound and is readily chipped by a blow from a pick.

No exact time for the removal of forms can be safely prescribed, nor is any such schedule wise in concrete work, because of the varying character of the work, the variations in atmospheric conditions, etc. Forms should, however, remain longer under beams and arches than around columns or walls, and longer under beams and arches of long spans than of short spans. The time that should elapse between the placing of concrete and the removal of the forms depends upon a number of things, among which are the following:

(1) *Variations in the Setting of Different Cements.* Some cements set and harden more rapidly than others. Forms may be removed earlier with quick-setting than with slow-setting cement.

(2) *The Richness of the Mixture.* Forms should remain longer under lean concretes than rich ones.

(3) *The Consistency of the Concrete, Whether Wet or Dry.* When mixed very wet, concrete sets and attains its strength more slowly than when mixed with a small amount of water. In other words, wet concretes require longer to harden than dry concretes.

(4) *The Quality of Concrete in the Member Considered, i. e., Its Own Dead Weight.* If dead load, that is, weight of the concrete

itself, is large, the forms must be left longer for concrete to attain sufficient strength. In other words, forms should never be removed until the concrete has set and hardened to such strength that it will sustain its own dead weight. Vertical members, such as walls thicker than 4 in., or columns, will bear their own weight when quite green, while horizontal members, such as floors, must harden until the concrete can sustain the dead weight and the load during construction.

(5) *The Strain Which Is to Come Upon the Work, i. e., the Load Sustained.* In no instance should forms be removed until it has been conclusively determined that the concrete has properly dried and possesses sufficient strength to carry its own weight (as mentioned above) and any weight that may be placed on it during the course of erection. That is to say, the forms should never be removed until the concrete has set and hardened to such strength that it will sustain its own dead weight and such live load as may come upon it during construction. The determination of this condition is a matter that calls for knowledge and judgment, as the length of time that should be allowed to elapse before removing the forms depends upon the load (or the nature of the stresses) to which the member will be subjected when the form is removed.

As to the effect of the load upon the time to elapse before removing the forms, it may be said that the nearer the load to be immediately sustained approaches the load for which the member was designed, the longer the forms should remain in position. For example, roof forms should remain longer than floor forms, floor forms longer than column forms, column forms of an upper story longer than those of a lower story, and column forms longer than footing forms. Forms may be removed earlier from under light than under heavy loads, and those which do not support loads may be removed as soon as the concrete has taken its final set.

(6) *The Humidity of the Air.* Concrete hardens more slowly under water or in a saturated atmosphere than in dry air. The setting of concrete is retarded by wet weather.

(7) *The Temperature.* Low temperatures delay the setting of concrete. That is to say, concrete hardens more and more slowly as the temperature falls. If the temperature be below freezing, the setting may be suspended (see page 349). In other words, concrete sets slower in cold weather than it does in warm weather, and therefore, forms may be removed earlier in warm and dry weather than in cold and damp weather.

The above and other circumstances must all be taken into account in deciding upon the safe time to remove forms.

Minimum Time Limits for Form Removal.—The following suggestions as to the time of removing forms in building construction are general and must be followed with judgment. That is to say, the following schedule is suggestive only, as the removal of forms should be left entirely to the judgment of the experienced engineer in charge of the work. The strength of concrete depends greatly upon the nature of the materials entering into its makeup; hence what is safe practice in one place may be dangerous in another.

(a) The *minimum* time for the removal of forms (not the supporting shores or props) should be as follows: For walls in mass work, 2 days; for thin walls, 3 days; for the sides of lintels, girders and beams, 3 days; for bottom of slabs, 4 days (for spans of 6 ft. or less plus 1 day extra for each additional foot of span); for columns, 2 days.

(b) The *minimum* time for the removal of shores should be as follows: For bottoms of beams and girders, 14 days, for spans of ordinary length.

(c) Should frost occur before the concrete has attained sufficient strength to enable the removal of the centering, the counting of time for this removal should start after the influence of frost has been entirely eliminated. That is to say, in counting the time that concrete should stand before removing the forms, days when the temperature is at or below freezing should be counted out, or at least allowance should be made for almost total suspension of the hardening process.

No schedule of removal can be blindly followed, and that given above is certain only when the conditions are right and as stated.

It may be further suggested that in dry, warm weather it is possible to remove the form work from light structures in from twelve to twenty-four hours. In large structures the time will vary from twelve to twenty-four days.

City Ordinances.—Removal of forms should comply with the city ordinances or regulations governing reinforced concrete construction and forms should not be removed until the approval of the engineer is obtained.

Tests to Determine the Hardness of Concrete.—To determine if concrete has sufficiently hardened to allow removal of forms several methods are adopted, depending upon whether the forms are for plain or reinforced concrete work.

A good method or rule to follow when laying wet concrete upon which no pressure is to come immediately is to determine whether it is sufficiently hard by pressing upon it with the *broad part of the thumb*. If indented, the concrete is too soft to permit of removing the forms.

Another method used to some extent for reinforced concrete work is to attempt to drive a *20-penny wire nail* into the concrete. If the nail bends before a penetration of 2 inches is reached, under medium heavy blows with a carpenter's ordinary claw hammer, it is usually safe to remove forms. It is sometimes required that such a nail or spike shall bend double before it has penetrated one inch.

Still another method or test to determine whether the concrete is set, is to strike it with an *iron bar* or *hammer*. The concrete should ring under the blow if it has a hard set. Of course, it is not necessary that it should test up in two weeks as hard as if it were six months old. An experienced inspector should be able to determine where the point of safety lies.

To an experienced inspector, scratching the concrete with a knife or striking it with a hammer gives a rough idea of the amount

of set, and therefore of its strength; but probably the only sure way to determine when the forms may safely be taken down is to make *test specimens—either cubes or beams*—at the same time the concrete is placed in the structure. Care must be taken to get identical mixtures and to store the test specimens under similar conditions to those obtained for the structure. The specimens are then tested from time to time to determine the growth in strength of the concrete. Such tests will also show whether the materials and the mixing were uniform. However, do not depend entirely on the hardness of test specimens as a guide for taking down forms.

Many large contractors mold a cube of concrete for each day's work and leave it standing on the finished floor exposed to the same conditions as the concrete in the forms (see page 303); examination of this sample block gives a line on the condition of the concrete in the work and on the probable safety of removing the forms at any time. These cubes should be tested, if necessary, to determine whether the concrete has the proper strength. This may be done by setting a minimum compressive strength that the concrete must attain before removal of forms, and when the cubes show the strength by test it is safe to remove formwork on the section from which cube was taken.

As an aid to judging when forms and supports may be removed safely, and when the concrete work may be used safely to carry extraneous weights or loads, beams about 4x6 in. x 3 ft. in length, made of concrete taken from batches which are being placed in the portions of the structure under consideration, may be tested.

An excellent way of knowing when the cement is fully set and the concrete properly hardened in *freezing weather,* is to cut out a chunk, place it on a hot stove and see whether it sweats and softens up. If it crumbles it means that the concrete has become frozen and forms cannot be removed until it has warmed up and set permanently.

Removing Forms in Freezing Weather.—When the necessary precautions are taken during freezing weather (see Art. 33), the forms may be taken down at the usual time, if, in the judgment of the engineer, the test prisms made under the same conditions as the concrete is made as mentioned above, has attained sufficient strength. As a general thing, however, the forms must remain in place much longer than in warm weather. Very cold weather delays setting indefinitely.

Special care must be used in removing centering when the concreting has been done in cold weather. In fact, extraordinary precautions should be taken where it is known that freezing weather occurred during the placing of the concrete. Falsework must never be removed while the concrete is frozen. If necessary, artificial heat must be employed to thaw the whole mass and the set and hardness determined before removing falsework. In other words, don't remove any forms until absolutely certain that the concrete is thoroughly hardened and that no portion is either soft or frozen. Failures have resulted on account of forms being removed from concrete that was frozen and appeared to be hardened due to setting.

The only sure way of knowing when the cement is fully set and the concrete properly hardened, is to actually test it by heating on a stove. To do this, it is necessary to remove small portions of the formwork and cut out chunks of concrete and place them on a hot stove as described above. For removal of forms in freezing weather, see page 364.

Organization of Form Removing Gang.—A competent and experienced foreman should be in charge of a special gang for removing forms at all times, and at no time are more men to be engaged in the striking of forms than the foreman can fully direct. No foreman lacking the required experience in this line, on high grade work, should be allowed upon the work. In other words, removal of forms should be done only under expert supervision.

It is of the first importance that the foreman in charge of removing forms should be of a high order of intelligence, and a man who can be relied upon to obey orders literally, for the reason that a mistake on his part is more likely to cause damage to life and property than a mistake on the part of any other foreman.

It is well to have a separate or special gang to remove forms for the reason that green concrete is particularly susceptible to injury from shock or sudden strain and most forms are usually removed while the concrete is comparatively green. Even a moderate weight or shock applied to the structure when the concrete is "green" may cause destructive results. This gang will in a few days become trained under an experienced foreman so that the work will not only be done with greater safety but also more rapidly. The procedure that this gang should follow will vary somewhat with the nature of the form work and will be considered in succeeding sections for several kinds of work. In all cases, this gang should be required to follow a regular system in its work, a system which may not be departed from without direct orders from the superintendent.

Superimposed Loads on Forms.—When forms are being removed, there must be no load upon the portion of the concrete affected in excess of one-sixth of the live load for which the portion affected was designed, unless temporary shores are left in to take care of such load.

Forms to Be Easily Removed.—Forms should be removed gently without chipping or jarring the concrete. Prying with bars or striking with a sledge must not be allowed as all jar and vibration must be avoided. With proper design and lubrication of forms they should ordinarily come away from the concrete with a moderate amount of sledge and bar work.

Care in Removing Forms.—Forms should be removed with great caution. Care in removing forms is essential for the reason that green concrete is very susceptible to injury from shock or sudden strain. Forms should be removed very carefully and gradually with close attention to the results and the concrete examined before general removal is ordered, so that if there is any sign of weakness the supports may be replaced, or if imperfect workmanship is discovered it may be repaired. With the careful removal of forms the defects or weak spots are revealed in such a manner as to permit their

being repaired without any damage. The inspector should be present while the removal of falsework is going on and constantly watch for imperfect places as the form is taken off.

The men engaged in the removal of the forms and falsework should be very carefully instructed in the danger and the disastrous results caused by carelessness, which will be liable to subject them to imprisonment. In the case of an accident they will be held for trial on the charge of criminal negligence.

Method or Manner of Removing Forms.—The method of removing forms will vary in detail with the character of the structure as will be described in succeeding sections. Forms when being taken down must not be dropped onto floors and knocked against columns and walls. The forms should always be eased down by a cable or other similar method. Always leave in place a few intermediate posts so as not to place the entire dead weight too suddenly on the beams and columns. A regular procedure should be followed in removing forms, and the work should be done by regular gangs (as mentioned above) so that the men become trained in the requirements and methods of the work.

Care must be exercised and precautions taken to prevent large masses of forms from falling on floors. In other words, the work of removing the forms, molds, and centering should be done with great care so as to avoid injury to the concrete. Care must also be taken to see that all portions of splintered forms adhering to the concrete work are removed.

Cleaning and Piling Forms.—The forms upon removal should be thoroughly cleaned of all cement (see page 238) and any necessary repairs should be made and the forms piled so they lie absolutely flat, and if possible, under cover, to prevent warping. The forms may be scraped with wooden scrapers and hot water, and given a coat of black oil (see page 241) and piled in some convenient place, preferably under cover.

Some discretion should be shown in the manner of piling forms, so that those needed first may be easily accessible.

COLUMN FORMS

Column forms, if removed first, should be so removed as not to disturb the beam and girder forms. In fact, it is desirable to remove the column forms first, since then any defect in the column may be detected and remedied before any considerable load comes upon it. This not only gives an opportunity to determine the soundness of the column casting, but also serves the further desirable purpose of baring the concrete to the curing and hardening action of the air. Columns should not be given their full load in less than five weeks after concreting.

Time of Removing Column Forms.—Column forms should not be removed in less than two (2) days, in summer; cold weather, four (4) days; provided girders are shored to prevent appreciable weight reaching columns.

Manner of Removing Forms.—The opposite sides of column boxes should be removed before any of the rest of the falsework, and these should be, where possible, the sides into which no beams are framed. In good weather this can be done in two or three days, and the column will then dry out quicker and be able to carry some loads. Where four beams frame into one column, two opposite sides of the column can be made so as to be removed first up to the bottom of the beam; but before doing so, erect a temporary shore or prop under the end of the beam which would be left unsupported.

SLAB, BEAM AND GIRDER FORMS

Floor Slabs and Sides of Beams.—Forms should not be removed from floor slabs of ordinary spans in less than seven days in summer weather with normal conditions. Slabs of reinforced concrete should preferably stand about two weeks of good weather before being called upon to support their own weight. Slabs of long span may require more than two weeks. In all cases leave, at least, one line of shores or props in the center of the floor slabs when removing floor forms. This precaution is often neglected and with very little reason considering the importance of the safeguard thus secured. Ordinarily the shores need not be left in place more than a week, so that the amount of lumber thus tied up is small.

Sides of beams and girders should not be removed in less than three days. The bottoms of beam and girder forms must remain in place until after the side forms have been removed, so as to inspect the sides of the beam without lessening the support of the beam against collapse. In other words, even if the side forms have been removed, it is absolutely necessary to leave the shores or props beneath the soffits of beams and girders, leaving the bottom form boards in place. This will afford an opportunity of not only inspecting the surface of the beams and girders, but to plaster up any cavities before the concrete is too hard. Of course, the side forms may stay on as long as the beams and girders are supported, but removing them within a few days after pouring the concrete permits the drying of the concrete much faster and expedites the work. In other words, when the side forms of beams and girders are removed and the concrete is exposed to the action of the air it drives out and attains strength more rapidly. The bottoms of the forms for beams and girders must be left in place and be supported until the beam has gained strength enough to be self-supporting, but the sides may be removed within a few days, or in some cases as soon as the concrete has taken an initial set. This should be left to the judgment of the engineer.

Beam and Girder Supports.—The original supports for all beams and girders should remain in place at least two weeks. Where practicable it is well to leave the shores or props under beams and girders for three or four weeks. Large and heavy beams should be allowed to stand longer than short ones, because the dead weight is a greater fraction of the load they are designed to carry. All beams and

girders having more than 30-ft. span from center to center of supports should be considered as special cases and should be subject to inspection of the Building Department before removal of supports. In spring and fall, when the weather is damp and chilly, it may be necessary to leave the forms and props much longer than cited above.

Freezing Weather.—The time at which props or shores may safely be removed from under beams and girders will vary with the condition of the weather, additional time, however, should be allowed for each and every day the thermometer registers any time during the day or night below 35° F. In some cases it may be necessary to leave the props under the beams and girders two or three months, or even longer, if the concrete has frozen and not obtained its natural set. In order to determine this point, the best course for the inspector to pursue is to break a small piece of concrete out of the work and take it to a warm place and leave it long enough to determine whether it has obtained its natural set by noticing whether it becomes soft and moist due to thawing of the frozen water in the concrete; this will be self-evident, and is a sure test of whether the concrete is frozen or set. In this connection, see page 247. If the sample concrete is frozen, the forms should remain until the concrete has thawed out and set naturally under the warmer weather.

Removal of Shores or Props.—Before removing the shores or props under any beam or girder, the column supporting it should be stripped, so that columns may be examined on all sides (see page 250), and at least one side of each beam and girder form should be removed in order to expose the concrete to view, so as to give evidence of the soundness and hardness of the concrete. The shoring underneath principal girders and beams should be the last to be removed.

A serious element of danger in reinforced concrete is the premature removal of the shores or props from under the forms. Many serious accidents have been attributed to this cause, although other causes have contributed to the disasters, such as improper design and bad workmanship. However, most of the accidents or failures of floors which have occurred have been due to mistakes in the removal of the supports of the forms before the concrete has properly set. Too much stress cannot be placed upon the importance of permitting the shores or props to remain under the concrete a length of time sufficient to insure against failure (see page 244). It is far better to lose a few days at this stage of the construction than to jeopardize the safety of the building by undue haste.

The contractor should reassure himself regarding the condition of the concrete before attempting the removal of the supports under any of the forms carrying a concrete floor system. The great temptation for the contractor, however, if the work is of any magnitude, is to remove the forms as soon as he needs them for another floor, and thus take chances of producing a failure. The inspector cannot be too strict in insisting upon the shores or supports remaining in position until the concrete has hardened sufficiently beyond a doubt.

Concrete in reinforced work should ring when struck with the hammer, before the supports are removed.

Care in Removing Shores.—Shores should be removed with great caution. They should be removed without jarring the structure by properly pulling the double wedges at the bottom (see page 223). They should be lowered gently and not allowed to drop heavily on to floors and thrown against columns. *Even a moderate weight or shock applied to the structure when the concrete is "green" may cause destructive results.* When shores are finally removed, they should be taken out for a beam or a panel at a time and under no circumstances must all shores under a floor be knocked down at haphazard or in rapid succession. The practice of ramming down the shores or props and thus letting all the centering crash to the floor must not be tolerated. There is absolutely no excuse whatsoever for such practice. Great care must be taken when the forms are removed; in fact, a large number of *"unaccountable"* cracks are due to carelessness in removing forms. In other words, falsework must be removed carefully, without jar to the concrete either by hammering on the boards or dropping heavy pieces on the floor below.

In many cases where reinforced concrete buildings have collapsed, with attendant serious damage and loss of life, the accidents have been caused by the improper removal of shores. Smashing the shores out is very nearly as dangerous as premature removal.

Removing Shores before Forms.—While it is customary to some extent to remove shores one at a time and then put them back again in order to permit the removal of the bottom boards of beam forms, etc., this practice should not be permitted. The reasons are obvious.

Precautions to Be Observed.—In removing forms the falsework should be lowered to such an extent as to permit the form to drop away an inch or two from the slab, in which position it should remain for 24 hours. While the wedges are being loosened the concrete must be carefully inspected.

If a load of any consequence is to come on the floor the shores or props should be left in place longer.

The shores should not be removed when any unusual load is on the floor. Materials should not be stored on floors that are not thoroughly hardened and self-supporting.

WALL FORMS

Massive Wall Forms.—It is sometimes possible in using dry concrete in warm weather, even if slow-setting Portland cement is used, to remove forms from retaining walls, pedestals, isolated pillars, etc., within 12 hours after placing the concrete, but care must be exercised that no blow or jar comes upon the fresh work; using wet or sloppy concrete the time will be increased to 24 hours. However, forms for massive concrete walls should not as a general rule be removed in less than one day, or when the concrete will bear pressure of the thumb without indentation. If indented, the concrete is too soft to permit of removing the forms. In other words, where there is no pressure against the wall the forms can generally be removed in from one to two days after the wall is completed, or just as soon as the

top concrete is so hard that it cannot be indented by the thumb. In cold or wet weather, more time will be required for the concrete to harden.

Thin Walls.—Forms for thin concrete walls should not be removed in less than two days for ordinary conditions; in cold weather, five days. If the wall is very thin and is to be subjected immediately to earth or water pressure, it may be advisable to allow the forms to remain for several weeks.

ARCH CENTERS

The centers should be struck when directed by the engineer, which direction should not be given until the masonry above them has been completed up to the level of the bottom of the coping. As a rule, arch-centering should be left in place as long as possible. Since concrete shrinks in setting and since wood shrinks in drying, there is a tendency of the concrete to separate from the centering unless the latter be kept wet. This wetting of the forms also supplies the water needed by concrete in setting (see page 240). When centers are removed, all supports between abutments and piers should be removed to the bed of the stream or to the surface of the ground.

Removal of Forms.—Forms which do not support loads may be removed as soon as the concrete has taken its final set. Lagging should be removed from spandrels, copings and railings as early as possible.

Time of Removing Centers.—There is no definite rule as to the length of time the centering should remain in place. In cases where the arch is to be given a form of brushed or rubbed finish (see page 397), so that the forms must be removed while the concrete is still green, or in cases where the structure is in several spans and the centering is needed for the others, it is removed earlier.

The time for removing arch centers should not be less than two weeks for spans up to 45 ft. if the arch is backfilled at once; when the center is not to be used again it is better to let it stand considerably longer. Arches of small spans, say to 15 ft. can have the centering removed in about a week's time. As a rule, centers should not be struck until the concrete has set for at least a month, and it is desirable that a longer period should elapse if possible; from two to three months if possible. In a number of cases centers have been removed at the end of ten days or two weeks, but this is a dangerous practice as a general thing, and should not be taken as a safe precedent. For very large arches the problem of removing the centering becomes a special one and should receive the special attention of the engineer.

Method of Removing Centers.—Arch centers should be removed without shock or jar to the arch ring. When forms are removed early, great care must be taken that they are lowered evenly and gradually, so that the arch ring can settle uniformly. While concrete begins to be self-supporting as soon as it begins to set, it does not reach its maximum strength for some time after setting, so that the removal of centers should be especially provided for. The devices usually employed are wedges or sand-boxes (see page 234). Wedges can be

driven out gradually, so that the strain comes upon the arch very slowly and evenly. Sand boxes are satisfactory if the necessary precautions are taken to keep the sand from packing or caking, due to the presence of dirt or cement (see page 234). Where wedges have been provided, they should be driven back equally, in order to lower the center uniformly. This is most easily accomplished by making a mark on the side of each pair of wedges before commencing to drive, and then moving each the same amount.

For very long spans the engineer will provide special instructions for striking centers.

MISCELLANEOUS FORMS

Conduits or Sewers.—Forms for conduits may be removed within two or three days, provided there is not a heavy fill upon the conduits. In some cases, forms for small arch work like sewers and culverts may be removed in 18 to 24 hours if dry concrete is used, and in 24 to 48 hours if wet concrete is used.

No center should be slackened until the backfill has been carried to such height, not less than one foot nor more than two feet above the top of the arch, as the engineer may approve.

Sidewalk Forms.—Forms for concrete sidewalks should be left in place until the concrete or mortar has set. (See page 473.)

Ornamental Molds.—Ornamental work should have the forms removed as soon as possible, so that defects can be plastered up (see Art. 30) and so that swelling of the wood will have less time to act. (See also Art. 54, page 507.)

CHAPTER V

INSPECTION OF STEEL REINFORCEMENT

It is not in the province of this book to rehearse the history of reinforced concrete, and the development of the numerous types of construction and systems now in use, nor to give methods of calculation or design, but simply to give such general and specific instructions as are necessary to insure the proper placing of the steel reinforcement in the structure after the work has been started. If the reader is interested in the history of the development of reinforcement for various structures or in the design of reinforced concrete structures, he can obtain the information from almost any of the standard books now published on the subject of Reinforced Concrete.

Art. 20. Delivery and Storage of Steel Reinforcement

DELIVERY OF STEEL

The steel should be delivered in such quantities and at such times as may be required by the work. It should correspond in dimensions, weight, and amount called for by the plans and specifications. This applies equally to plain reinforcing rods and built-up members.

Manner of Delivering Steel.—Reinforcing steel should be sorted, bundled and labeled when delivered; that for a concrete building, for example, is generally delivered at the site in the following manner: All loose bars for floor slabs, etc., are bundled and tagged, showing their respective sizes and lengths. All bars for beams, girders, etc., whether loose or built up, are delivered in a similar manner. All column bars are bundled and tagged separately for each section of column. All hooping for columns is tagged with column number and section. All wire mesh reinforcing is shipped flat and cut to the required widths and lengths. The light reinforcement, such as the stirrups and the wire ties, may be delivered in stock lengths and cut up as desired.

Bending of Steel.—It is generally preferable to have the bars bent before they are delivered, but in case this is not done, the contractor is required to provide such facilities and labor as may be necessary to bend the bars in the field.

Condition of Delivery.—All steel should be free from heavy rust or scale. The inspector should carefully examine the shipments to see that the bars are not badly rusted, and if the rust has accumulated in quantity, he should have it cleaned off with a steel brush or dipped in an acid bath as described on page 263.

STORAGE OF STEEL

As soon as the steel is received at the site, it should be checked, assorted and stored in such a manner that it can be inspected.

Assorting Steel.—If the material that has been carefully ordered from the drawings, as well as certain lengths of bars intended for certain portions in the work, are delivered in such a way as not to indicate where they are to be used, the inspector should have them carefully sorted and then marked or tagged to correspond with the marks on the drawings. On the other hand, if the steel is not marked, or is improperly marked, a letter to that effect should be sent to the company furnishing the reinforcing material, specifying the exact nature and extent of the failure properly to mark the bars. It is advisable always to do this before the bars are needed for bending, working or placing in the forms. In other words, the absence of marks on bent bars or built-up members should be reported promptly and such pieces should be laid aside, if possible, so they can be marked upon receipt of definite information.

If care is not exercised in sorting bars that have been ordered according to the plans, it will frequently be found that bars of certain lengths have been cut for positions in which shorter bars were required, and that upon the final operation of the building there is no steel reinforcement of sufficient length on hand to finish the work. The author has found this to be particularly true where expanded metal, which comes in sheets of certain sizes, is employed in reinforcing floor slabs. If these sheets are not properly sorted for placing in the correct position, there will be extravagant laps in many places, and where the steel reinforcement for the top story of the building or the final operation in the structure is about to be placed, it will be found to be too short for the spans and that a great bulk of the steel reinforcement has been wasted.

The careful sorting out of the steel reinforcement not only tends to promote economy, but also largely assists and facilitates the work when it is necessary to commence the operation of bending and placing.

Storage of Steel.—The steel reinforcement to be used in concrete construction should be stored in such a way that bundles of bars of the same size will be kept together on racks or in piles. Where there is plenty of room the most convenient way to take care of the steel is to put it in piles on the ground with posts alongside telling the size and length. If there is not much room then a steel rack must be made. These racks are simple and do not require description. Preferably they should be covered over in such a manner as to protect the steel from injury. Roofing over the steel racks not only protects the steel from rain and snow, but also enables the men to work dry-shod in stormy weather. But whether the material is laid on the ground or put on racks under cover, one man should be appointed whose sole duty is to look after the receiving, checking and storage of steel, and if this is not done there will be trouble.

As much care should be taken with the storage of the reinforcing

steel as with the other materials used in the work. Bars of each size and length should invariably be stored by themselves. They should also be so stored that those portions needed first may be reached without handling other material or bars. This point is important.

A list should be kept of all the steel reinforcement on the job, and as the various pieces are taken from the stock, they should be checked off.

Protection of Steel—The steel should be protected from rust, dirt, oil, paint, etc. That is to say, reinforcing material should be protected from the weather, but must not be oiled or painted.

Art. 21. Inspection and Tests of Concrete Reinforcing Bars

The steel should be tested, invariably. In one particular building with which the author was connected, there were lots of steel which tests showed to have a dozen different elastic limits, from 28,000 to 45,000 lbs. If a building is designed for 45,000 lbs. steel, and then it runs only to 28,000 lbs., something is likely to happen. The value of the elastic limit should depend entirely on the allowable compression in the concrete.

MILL INSPECTION AND TESTS

Inspection and tests of concrete reinforcing bars should be made at the place of manufacture prior to shipment.

Process of Manufacture.—Steel may be made either by the open-hearth or Bessemer process. Bars should be rolled from billets. No material from old rails, scrap, etc., should be accepted.

Chemical and Physical Properties.—The chemical and physical properties should conform to the limits fixed by the Association of American Steel Manufacturers (1910), which are as follows:

Properties considered.	Structural steel grade. Plain bars.	Structural steel grade. Deformed bars.
Phosphorus, maximum:		
Bessemer	.10	.10
Open-hearth	.06	.06
Ultimate tensile strength, lbs. per sq. in.	55,000-70,000	55,000-70,000
Yield Point, minimum, lbs. per sq. in.	33,000	33,000
Elongation, per cent. in 8-in., minimum	1,400,000 / T. S.*	1,250,000 / T. S.
Cold bend without fracture:		
Bars under $\frac{3}{4}$-in. in diameter or thickness	180° d.=1t.	180°d.=1t.
Bars $\frac{3}{4}$-in. in diameter or thickness and over	180° d.=1t.	180°d.=2t.

Properties considered.	Hard grade. Plain bars.	Hard grade. Deformed bars.	Cold twisted bars.
Phosphorus, maximum:			
Bessemer	.10	.10	.10
Open-hearth	.06	.06	.06
Ultimate tensile strength, lbs. per sq. in.	80,000 min	80,000 min	Recorded only
Yield Point, minimum, lbs. per sq. in.	50,000	50,000	55,000
Elongation, per cent. in 8-in., minimum	1,200,000 / T. S.	1,000,000 / T. S.	5%
Cold bend without fracture:			
Bars under $\frac{3}{4}$-in. in diam. or thickness	180°d.=3t.	180°d.=4t.	180°d.=2t.
Bars $\frac{3}{4}$-in. in diam. or thick. and over	90°d.=3t.	90°d.=4t.	180°d.=3t.

* T. S. = tensile strength.

Allowable Variations.—If the ultimate strength varies more than 4,000 lbs. from that desired, a retest should be made on the same gauge, which, to be acceptable, should be within 5,000 lbs. of the desired ultimate.

Chemical Determinations.—In order to determine if the material conforms to the chemical limitations prescribed above, analysis should be made by the manufacturer from a test ingot taken at the time of the pouring of each melt or blow of steel, and a correct copy of such analysis should be furnished to the engineer or his inspector.

Yield Point.—For the purpose of these requirements, the yield point should be determined by careful observation of the drop of the beam of the testing machine, or by other equally accurate method.

Form of Specimens (Deformed Bars).—Tensile and bending test specimens may be cut from the bars as rolled, but tensile and bending test specimens of deformed bars may be planed or turned for a length of at least 9 in. if deemed necessary by the manufacturer in order to obtain uniform cross-section.

Cold Twisted Bars.—Tensile and bending test specimens of cold twisted bars should be cut from the bars after twisting, and should be tested full size without further treatment, unless otherwise desired.

Hot Twisted Bars.—If it is desired that the testing and acceptance for cold twisted bars be made upon the hot twisted bars before being twisted, the hot rolled bars should meet the requirements of the structural grade for plain bars as mentioned above.

Number of Tests.—At least one tensile and one bending test should be made from each melt of open-hearth steel rolled, and from each blow or lot of ten tons of Bessemer steel rolled. In case bars differing ⅜-in. and more in diameter or thickness are rolled from one melt or blow, a test should be made from the thickest and thinnest material rolled. Should either of these test specimens develop flaws, or should the tensile test specimen break outside of the middle third of its gauged length, it may be discarded and another test specimen substituted therefor. In case a tensile test specimen does not meet the requirements, an additional test should be made.

Bending Test.—The bending test may be made by pressure or by light blows.

Modifications in Elongations for Thin and Thick Material.—For bars less than 7/16 in. and more than ¾ in. nominal diameter or thickness, the following modifications should be made in the requirements for elongation:

(a) For increase of ⅛ in. in diameter or thickness above ¾ in. a deduction of 1 should be made from the specified percentage of elongation.

(b) For each decrease of 1/16 in. a deduction of 1 should be made from the specified percentage of elongation.

(c) The above modifications in elongation should not apply to cold-twisted bars.

Number of Twists.—Cold-twisted bars should be twisted cold with one complete twist in a length equal to not more than 12 times the thickness of the bar.

Finish.—Material must be free from injurious seams, flaws or cracks, and have a workmanlike finish.

Variation in Weight.—Bars for reinforcement should be subject to rejection if the actual weight of any lot varies more than 5 per cent over or under the theoretical weight of that lot.

Defective Material.—Material which, subsequent to the above tests at the mills and its acceptance there, develops weak spots, brittleness, cracks or other imperfections, or is found to have injurious defects, should be immediately rejected at the site of the work.

FIELD INSPECTION AND TESTS

The inspector should see that the steel reinforcement offered for use on the work is of the character and grade specified, either by affidavits from the makers of the steel, copies of the mill tests of the material, or otherwise, as may be required by the engineer. In cases where special conditions make inspection of reinforcing steel at the place of manufacture impracticable, field or job inspection may be substituted, subject, however, to the approval of the engineer. In such cases, the following requirements should be met:

Number of Physical Tests.—Test by a competent inspector should be made of each carload of reinforcing material used in the work; at least one sample of each size cross-section of the various styles of reinforcing material contained in each car should be subjected to one tensile test and to one bending test.

Report of Tests.—A report of the above tests showing the elastic limit, ultimate strength and elongation in eight (8) inches of each specimen should be submitted to the engineer for his approval.

Deficient Material.—If the results of any of these tests are deficient, either the deficient material shall be rejected or the amount of reinforcement, where such deficient material is used, shall be increased in such proportion as to secure a section in which the stresses induced shall not exceed by over ten per cent (10%) the limit allowable.

Tensile Test.—The steel should be subjected to a tensile test at some laboratory approved by the engineer, and should meet the requirements given on page 258 for Mill Tests.

Fracture.—All broken test pieces of steel reinforcement must show a silky fracture of uniform color.

Bending Test.—The reinforcement should be subject to a bending test, which may be easily made on the job, and no steel which fails to pass this bending test should be used under any circumstances. All bending should of course be done cold. For high-carbon (hard grade) steel it is usually specified that the bar must bend cold around a pin four times the diameter of the bar without showing signs of distress. Good cold twisted bars will easily bend around a pin twice the diameter of the bar. Three or four diameters are, however, more commonly specified. Soft stock should fold flat upon itself without showing signs of cracking or checking.

The bending test is very important, as practically all the bars are bent on the job. For additional bending tests, see page 258.

Net Area.—The net area of cross-section of finished steel reinforcement should not be less than 95 per cent of the area shown in the approved design.

Art. 22. Placing Steel Reinforcement

Concrete is weak in tension, i. e., a strain tending to pull it apart, but it is strong in compression, i. e., a strain tending to crush it together. Steel reinforcing material is placed in various forms near the tension sides of structural members to resist the tensional stresses. It may assist also in resisting the shear, the diagonal tension, and occasionally the compression stresses, as in doubly reinforced beams; and it gives additional compressive strength when used in columns.

TYPES OF REINFORCEMENT

Varieties.—There are a number of types or styles of reinforcement now on the market which may be classified as follows: (1) Plain bars either medium or high carbon (hard grade) steel; (2) Plain bars deformed or cold worked to secure deformation. This classification includes cold twisted and hot twisted square bars; (3) Special patented types of plain or deformed patented bars; (4) built up bars, meaning thereby combination of various sized members in order to utilize the quantity of steel to the best advantage; (5) built up (unit) frames composed of bars of various sizes, generally used for beams, girders and columns; (6) floor slab reinforcement of sheet metal, sheared, punched or expanded in order to distribute the steel through the mass and delivered in sheets; (7) cold woven wire similar to fencing material delivered in rolls; (8) secondary reinforcement in the way of hoops or bands for columns, stirrups for beams, and spacers for rods, all of which may be made of hoop iron or heavy wire; (9) steel corner bars consisting of a round nose with a lug extending back into the concrete, used for curbs, steps, columns, etc.; (10) structural steel shapes, such as angles, beams, channels, etc.

"Loose-Bar" Method.—In the "loose-bar" method or system, as generally practiced, the reinforcement is designed out of separate bars or rods to be shipped as individual pieces to the job and there bent to the proper shape and wired together in place in the forms. This system comprises round rods, square and flat bars, and the various patented deformed bars. There are a number of prominent systems of construction that are built up of loose bars, the assembling being done in the field. With separate bar reinforcement the erector may either place the reinforcement complete in the form of wire-tying the bars to each other, to temporary braces or templates and to the forms, or he may insert the various pieces of reinforcement in the concrete as the pouring advances, depending on the surrounding concrete to retain them where inserted. Generally a combination of both methods is employed.

Particular attention must be given to loose-bar reinforcement to insure that it is accurately and properly supported in position, so

that all parts shall remain in true relation and alignment until locked in the setting concrete. This is easier said than done. Owing to the inability of inspectors and superintendents to be everywhere at one time, and very often to the incapacity of these men, reinforcing rods or bars are in many cases incorrectly placed or left out altogether. It is not hard to understand what such oversights mean to the safety of the structure. Such device or devices must, therefore, be used as will absolutely prevent the bars from approaching the forms beyond the limits specified for protection (see page 266), and at the same time maintain a uniform and accurate spacing of the bars throughout the length of the members.

If the inspector has charge of work when loose bars are employed, he should insist on having the reinforcement stacked in racks with separate compartments for the various sizes as mentioned in Art. 20, so as to keep each size separated from the others, and to have the contractor place in position all the reinforcement for a certain section of the work before concreting is performed. This will give the inspector an opportunity to inspect a section of the work in its entirety and not piecemeal, as by the latter method, should the inspector call the contractor's attention to bars not being in place, he is very apt to be assured by the foreman that the bars will be in before any concrete is poured, and if, by chance, the inspector was on another part of the work when the concrete was poured, he would be at a loss to know whether his instructions were carried out. Also, it very frequently happens that work is performed overtime when the inspector may not have an opportunity to be on hand. The author's experience has proven that the loose-bar system of reinforcement is the most difficult to superintend.

"Assembled Unit" System.—Instead of placing the reinforcement piece by piece as described above, it may be placed as a complete unit in the form before any concrete is poured. In the assembled unit systems the reinforcement for each member, comprising the number, size and location of the bars, is carefully manufactured either in a shop or on ground adjacent to the building and put into the forms as a unit. In some of the systems these unit frames are provided with connections so that the adjacent reinforcement may be joined firmly together, thus providing the necessary continuity of the structure. In other words, in addition to having the beam and girder reinforcement tied rigidly together, the column and slab reinforcement is tied to that in the beams and girders, thus having all the reinforcement in the building tied together. With unit frame reinforcement the erector has nothing to do but to line and level up the frames in the forms, place such temporary braces as are needed to hold them true, and make the end connections with abutting frames. Such frames are usually provided with "chairs" (see page 266) to hold the bottom bars up from the form so that little bracing or none is required.

The use of unit frames will greatly facilitate the placing of reinforcing steel, for most of the fastening together is done before insertion in the forms as mentioned above, thus reducing to a min-

imum the liability of wrongly placing the steel. The inspection will also be greatly facilitated. However, most of the general instructions given in this article apply with equal force to either system of reinforcement, i. e., loose-bar and unit frame.

GENERAL REQUIREMENTS

The processes in detail of placing reinforcement are particularized in the several sections that follow; they will differ for nearly every job. Here, therefore, general rules or instructions only will be given.

Handling Reinforcement.—All metal which has been bent or otherwise injured in handling or in transit should be carefully repaired before being used. Reinforcing bars must be straight and free from flaws in any degree calculated to impair their strength.

Replacing Broken Bars.—Should any bar be broken it must be laid aside and another bar of the same length and cross-section procured without delay.

Cleanliness of Steel.—The steel reinforcement, before being placed in forms, should be thoroughly cleaned from loose, scaly rust, dirt, oil, paint, or coating that may be detrimental to the positive adhesion of the concrete to the steel, and care should be taken to keep it in this condition and thoroughly protected from moisture until the concrete is placed. A thin film of rust, which facilitates the forming of a hard film or a coat of ferro-calcite, and increases the adhesion of the concrete, should not cause the rejection of a bar, but any bar on which rust scales have begun to form should be immediately rejected, unless such scales are thoroughly removed with wire brushes or by other means. The reduced section of badly rusted steel thus cleaned should receive consideration.

Concrete which has lodged on the steel reinforcement and hardened during the previous work should be entirely removed before the reinforcement is finally concreted in.

Painting or Oiling Bars.—No steel reinforcement should be painted or oiled, as either will lessen the adhesion of the concrete. Grease or foreign matter of any kind should never come in contact with the steel.

Some specifications require that the steel reinforcement be dipped in a bath of cement grout before being installed in the forms, but by careful manipulation during the placing of the concrete, this extra handling and cost is unnecessary and should be done away with. The coating of steel with grout to preserve it from rust is a doubtful expedient. The thin layer of cement dies out and does not set properly. It may not bond with the cement of the concrete. It is better to have the fresh concrete come in contact with the steel. A more intimate union is effected. The ends of bars which are left protruding for splicing may be, if they are likely not to be connected up for some time, painted with cement grout to diminish rusting, which should afterwards be scraped off before connections are made.

Methods of Cleaning Reinforcement.—All heavy rust and mill scales may be removed from the reinforcing metal by hammering,

steel scrapers or brushes, pickling in a weak solution of hydrochloric acid, or by some other equally efficient means of cleaning the metal, before being covered by the concrete.

Use of Pickling Bath.—Rusty or dirty steel, if permitted by the specifications, may be cleaned by pickling in a bath consisting of 1 part commercial sulphuric acid to 5 or 6 parts of water, or other proportions, depending upon the amount of rust on the bars. Bars must be washed thoroughly in clean water after the bath and before placing in the concrete. In other words, where the bars are pickled in acid they should be thoroughly washed afterwards so as to remove the acid before depositing the concrete. Any remaining traces of acid may be detected by tasting the water left on the surface of the bars.

Cleaning Forms.—No steel should be placed until the forms have been thoroughly cleaned and inspected. Forms must be cleaned of all dirt and shavings and care must be taken to prevent new dirt and shavings from coming into the forms. (See Art. 18.)

Assembling Reinforcement.—The steel reinforcement should be so assembled that the exact number, size, form, spacing and location of bars, stirrups, ties, spacers, etc., called for by the engineer's plans is adhered to in every member. Should any discrepancy be noted in regard to the reinforcement of similar members, it should be brought to the immediate attention of the engineer in charge of the work.

Carelessness in Placing Reinforcement.—The design of a concrete structure contemplates the placing of the steel reinforcement in exactly the position shown by the plans and cross-sections of the various members. The careful placing of bars is one of the most important features of reinforced concrete construction, and one which is too often neglected because of the expense of doing it right. The greatest element of danger exists in the misplacing of the reinforcement, leaving it out of the forms altogether, or in placing it so carelessly as not to have it near the position upon which the calculations were based. Carelessness frequently exists in not properly lapping the steel reinforcement at junctions.

It is the inspector's duty to insist upon the reinforcement being accurately placed, and any carelessness on the part of the contractor in this should be sufficient grounds for the engineer to require the removal of the work, and the replacing of it correctly. Haphazard and slovenly methods of placing steel reinforcement are unjustifiable and must give way to more scientific conditions. The displacement of the reinforcement, either by accident or design to facilitate the placing of the concrete, may cause the failure of the structure.

Results of Inaccuracy in Placing Reinforcement.—Steel reinforcement must be set accurately in place in accordance with the detailed drawings for that purpose. A great many workmen seem unable to appreciate the importance of exact, not approximate, placement of the steel. Results of not taking proper precautions to insure the exact, not approximate, position of the steel in the finished structure, are:

(1) Congestion of bars in bunches, not allowing proper amount

of concrete to encase each bar; crowding of a bar or bars to one side of the form, resulting in slight or no protection to the steel and insufficient bond.

(2) Position of one or more bars either too low or high, in the one case giving insufficient protection and bond, and in the other reducing the efficiency of the steel itself (see pages 277 and 280), since the closer to the neutral axis the bars may lie, the less they come into action. Designers are usually quite conservative in their allowance for protection of steel by fireproofing concrete below it, and the contractor better err on the safe side and take advantage of this allowance rather than to keep above same.

(3) Uneven bedding so that while one end may be all right the other may be far too high.

(4) Bars too far one way, falling short of one support and overlapping the other an unnecessary amount.

(5) Mistakes in amonnt and size of steel, as called for by the design, attended by even more serious results—unless steel is positioned before attempting to concrete it cannot be checked either in amount, correctness of sizes, or position.

Number of Bars.—The inspector should see that the exact number of bars, stirrups, ties, etc., called for by the engineer's plans, goes into every member. In other words, the amount of the reinforcing, that is, the number of bars used, should be frequently checked to see that the plans are followed. In a section having 50 bars, it is very easy for the contractor to leave out half a dozen.

Sizes of Bars.—The inspector should see that the sizes of bars used in any member correspond exactly to the engineer's plans. The wrong reinforcement may be used. It is an easy matter to make an error of ⅛ in. in the selection of bars. This may mean a decrease of 25 to 50 per cent in strength. When made-up frames are used error is equally liable in their selection.

Form of Bars.—The form of each bar should be the exact form called for by the engineer's plans. Deformed bars should have a deformed cross-section, that is, the various cross-sections should be of different shape or their centers should not lie in the same axis.

Spacing of Bars.—The bars making up the reinforcement of any member should be spaced exactly as shown by the engineer's plans. The spacing should be carefully followed by the inspector. In other words, bars must be spaced the proper distance apart and away from the face of the form work and must be securely held in that position so as not to be disturbed by the placing of concrete.

The clear spacing between parallel reinforcement in beams and girders should not be less than 1¼ ins. No reinforcing bars should be closer together than 2¾ diameters, center to center.

In spacing the bars, in slabs or columns, templates should be used to make certain that all connections will fit accurately.

Bearing at Ends of Bars.—Care must be taken to see that all bars have a sufficient bearing at ends or over supports. Failure to do this frequently results in difficulty and trouble.

Embedment of Reinforcement.—Steel reinforcement should be em-

bedded to a depth of at least 1 in. from any surface, unless otherwise shown on the detailed drawings or stated in the specifications. Care must be taken to keep all bars at such distance as the engineer directs from the nearest exposed face.

Thickness of Concrete Covering.—The minimum exposed concrete covering of all faces for steel reinforcement used in building construction is generally as follows: $\frac{3}{4}$ in. for slabs; $1\frac{1}{4}$ in. for beams and girders; $1\frac{1}{2}$ in. for columns and walls, and 2 in. for foundations.

Placing Reinforcement in Proper Position.—The most imperative duty of the inspector is to see that no detail of the engineer's design of reinforcement is varied from in placing the reinforcement in the structure. The contractor must be required to follow very closely the plans or the instructions of the engineer in the placing of the reinforcing material, both as to size, spacing and placing relatively to the surfaces; and where no measurements are given on the drawings the contractor must be required to follow the instructions given by the engineer. The steel reinforcement must be placed the proper distance from the bottom and sides of the forms and in the position required in the finished structure, and each piece or member so firmly fixed as to positively prevent any subsequent displacement when concrete is being poured.

Heavy reinforcement should be placed within the forms before the form tie-rods are placed, as these tie-rods frequently interfere with the placing of heavy reinforcement.

It is absolutely essential that the steel be placed in proper position so that the line and level of all bars and of the reinforcement as a whole are accurate. If either the number, size or spacing of the reinforcements is varied from, the strength of the concrete member will not be what it was designed to be and injury results. In other words, the inspector shall insist that the reinforcing steel be properly positioned as called for by the design, and suitably secured and carefully checked before attempting to pour concrete. In no case should a greater variation in height than $\frac{1}{2}$ in. be allowed, or in other dimensions of over $\frac{3}{4}$ in. No steel must appear on the surface of the work.

The proper reinforcement of the members is of the highest importance and nothing can be permitted to interfere with it.

Metal clips or cement blocks should be used for keeping the steel bars the proper distance away from each other or from the face of the form. The ordinary way is to have a laborer raise the bars from the forms with his shovel-blade or a hook made for the purpose, but such methods rarely result in satisfactory work, as there is no gauge to determine the final position of the bars and if the concrete flows under them in too large a quantity their efficiency will be impaired.

Spacing "Chairs."—Spacing "chairs" and clips for bar reinforcement should be made of a heavy weight and a good quality of sheet steel. They should have ample strength against crushing down under such loads as are likely to come on the reinforcement. The bottom edges of the chair should be bent to form flat feet and prevent cutting into the form boards when used to support floor reinforcement. For wall and column reinforcement, the bending of the

bottom edge of the chair to form feet may be omitted, and for spiral hooping the slots for the spiral rods may be cut to pitch so that the chairs set straight with the vertical bars. The chief objection to metal spacers and separators is that they form a straight joint in the fireproofing and also conduct heat to the bars. (See page 274.)

Support of Metal Separators.—All metal separators used to keep the reinforcement at the right distance from the forms should rest on a piece of galvanized iron or else a rust spot will show on the under surface.

Supply of Supports.—Enough supports should be furnished to prevent sagging of the reinforcement.

Wooden Blocks.—Wooden blocks should not be used unless absolutely necessary for the reason that, remaining in the concrete as they are liable to do, a weak spot will be developed.

Bending Steel Bars.—All reinforcing bars must be bent before they are placed in position. Work should be so arranged that all bars of the same size and shape will be bent at the same time. This will avoid remeasuring, resetting of templates, etc. The bending of all bars should be done in such a manner that they will not break or crack at the end. The bending force should be applied gradually and not with a jerk. In other words, bending must be done with great care, so that no appreciable strength is lost thereby, being done with large radii in the curves so that no injury results. While the difficulties incidental to bending heavy steel bars to sharp corners usually prevent such practice, it is different with the U-bars used for stirrups and other light steel, and many half broken bars of the lighter sections have without doubt found their way into important work.

Bending must be done with absolute accuracy in accordance with the dimensions and forms shown on the detail sheets for the various portions of the structure. The bends should be accurate in line and plane.

Reinforcing bars can usually be bent cold, but for sizes 1½ in. and upward some makes of bars require heating; this can be done by laying the bars side by side on the ground and arranging sticks and shavings on top of them in a strip 18 in. to 2 ft. wide across the portion where the bend is to be. If the bars are heated and blacksmith work is done, care must be exercised that the steel is not burned in the operation, otherwise it should be condemned. Warming up to a low cherry red should be the highest heat permitted. In other words, only moderate heating should be allowed, which in most cases is all that is required. All ordinary bending, however, should preferably be done cold. It is very important, especially in bending large bars, that the bending force be applied gradually and evenly and not with a jerk.

All bends and angles should be carefully examined for cracks before placing the bars in position. Cracked bars must be replaced. When any bars are broken they must be replaced.

Bar Benders.—Several devices are on the market which facilitate the bending and shaping of reinforcing bars. Bending machines

should be required to bend any kind of a steel bar up to $1\frac{1}{4}$ in. in diameter to any angle required.

A simple cast iron block for bending bars may be made of a block of metal with a longitudinal groove cut in it. The block is attached rigidly in a horizontal position to a work bench, the bar to be bent is dropped in the slot, a piece of extra heavy pipe is then slipped over the end of the bar, and a couple of men can bend it to the required angle. A bending block may also be made of an iron plate with two angles riveted to it back to back to form a slot. Stirrups when bent by hand may be bent on such a plate, the angles, of course, being small and only far enough apart to admit of the size used for stirrups.

Splicing or Lapping of Bars.—When the reinforcing bars required are very long the individual bars must be spliced. The lap should be great enough to develop the strength of the steel, or at least 40 diameters. Contractors are wont to ignore this provision of the specifications and reduce the lap to about 20 diameters, thus effecting a saving in steel. The splicing of bars should be done exactly according to the engineer's plans. No splices whatever should be permitted except at points shown on plans. Various forms of splices are in use and if not definitely instructed by the plans and specifications the inspector should learn from the engineer what form or forms will be acceptable (see Fig. 20).

Where extra splice bars are called for, care must be used to see that they are not omitted.

The length of lap required for splicing of reinforcing bars in tension should be determined on the basis of the safe bond stress and the stress in the bar at the point of splice; or a connection should be made between the bars of sufficient strength to carry the stress. Splices at point of maximum stress should be avoided.

Headers.—In all work built between forms, in which the horizontal bars run farther than the lengths of the forms for that particular section of work, the headers against which work ends should be perforated at the proper places and the bars should project through the same for a minimum distance equal to the least lap allowed for the size of the bar, and all of different lengths, so that in no place will laps occur nearer to each other than 2 ft. in adjoining bars in the same plane. (See page 280.)

Welding of Bars.—No welding of reinforcement except in column hoops should be permitted without special permission from the engineer. Welding should, however, be avoided if possible, and is permissible at such points only where the stress is rather insignificant.

Protruding Ends of Bars.—The ends of bars which are left protruding for splicing should be, if they are likely not to be connected up for some little time, painted with cement paint to diminish rusting and guard against being bent or loosened. Throughout the work care must be exercised to prevent disturbing bars, portions of which are embedded in fresh concrete, otherwise the adhesion between the bar and the concrete will be broken.

Fastening Reinforcement.—All reinforcement should be securely

fastened to preserve spacing, location, alignment, etc. Where a wet gravel concrete is used, the need of secure fastening for the bars is particularly great. Such a concrete flows easily and if bars are merely laid in place they will be swept aside as though they were chips. In other words, the reinforcing material should be so supported during construction as to insure that it will occupy its designed position in the completed structure. Braces, blocks, suspenders, spacers, ties, etc., should be used in ample number to make certain of this feature. All temporary fastenings should be removed as fast as the concreting reaches them, in order to prevent any unsightly, dangerous or deteriorating matter remaining in the concrete. Wherever practicable all the reinforcement should be put in place in the forms and securely fastened in correct positions by wiring or otherwise before the placing of the concrete is begun.

All wiring, straps, braces and templates required for the proper holding of the reinforcement in place should be furnished by the contractor in a manner entirely satisfactory to the engineer.

Wiring Reinforcement.—The wiring of reinforcement at intersections should be done carefully and strongly, using No. 16 or No. 18 B. & S. gauge soft black wire, such as stove pipe wire. Reinforcing bars should be wired together at laps and intersections, where directed. The wire should be cut into lengths of about 8 in. and preferably two pieces used at intersections.

Tagging Reinforcing Bars.—When the bars are cut and bent to proper shape, each individual bar in every beam and girder, or group of bars in columns, slabs, walls, footings, etc., should be tagged with a cloth tag and wired securely to the bars (for beams and girders), or each bundle of bars, and marked with the proper number of the structural member, and the tags should be left on after the bars are placed in proper position in the forms. The engineer or his inspector should carefully examine the bars after they have been placed, personally remove the tags, after which the concrete may be placed.

Placing Concrete.—The contractor should be required to take the greatest care in the erection of the reinforcement, keeping a constant eye on it at the point where the concrete is being placed, to see that all the bars are in the proper location. Concrete should not be deposited in any portion of the work until all the reinforcement for that section of work is in position and has been checked over to see that it agrees with the drawings. It is cheaper to delay the work than to cut out work already done. See that the bars are clean when installed in place, ready for concrete. Care must be taken not to knock the bars out of position while concreting. In this connection, see Art. 25.

The steel work must be kept sufficiently ahead of the concrete work to give ample time for inspection. In fact, all steel must be placed ahead of the concrete except where instructions are given to the contrary (in very exceptional cases only). In such cases, the bars must be put in at the point designated by the engineer on his drawings, and they must be bedded solidly in the concrete, and all parts of the bar must have contact and adhesion with the concrete.

should be required to bend any kind of a steel bar up to 1¼ in. in diameter to any angle required.

A simple cast iron block for bending bars may be made of a block of metal with a longitudinal groove cut in it. The block is attached rigidly in a horizontal position to a work bench, the bar to be bent is dropped in the slot, a piece of extra heavy pipe is then slipped over the end of the bar, and a couple of men can bend it to the required angle. A bending block may also be made of an iron plate with two angles riveted to it back to back to form a slot. Stirrups when bent by hand may be bent on such a plate, the angles, of course, being small and only far enough apart to admit of the size used for stirrups.

Splicing or Lapping of Bars.—When the reinforcing bars required are very long the individual bars must be spliced. The lap should be great enough to develop the strength of the steel, or at least 40 diameters. Contractors are wont to ignore this provision of the specifications and reduce the lap to about 20 diameters, thus effecting a saving in steel. The splicing of bars should be done exactly according to the engineer's plans. No splices whatever should be permitted except at points shown on plans. Various forms of splices are in use and if not definitely instructed by the plans and specifications the inspector should learn from the engineer what form or forms will be acceptable (see Fig. 20).

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Headers.—In all work built between forms, in which the horizontal bars run farther than the lengths of the forms for that particular section of work, the headers against which work ends should be perforated at the proper places and the bars should project through the same for a minimum distance equal to the least lap allowed for the size of the bar, and all of different lengths, so that in no place will laps occur nearer to each other than 2 ft. in adjoining bars in the same plane. (See page 280.)

Welding of Bars.—No welding of reinforcement except in column hoops should be permitted without special permission from the engineer. Welding should, however, be avoided if possible, and is permissible at such points only where the stress is rather insignificant.

Protruding Ends of Bars.—The ends of bars which are left protruding for splicing should be, if they are likely not to be connected up for some little time, painted with cement paint to diminish rusting and guard against being bent or loosened. Throughout the work care must be exercised to prevent disturbing bars, portions of which are embedded in fresh concrete, otherwise the adhesion between the bar and the concrete will be broken.

Fastening Reinforcement.—All reinforcement should be securely

fastened to preserve spacing, location, alignment, etc. Where a wet gravel concrete is used, the need of secure fastening for the bars is particularly great. Such a concrete flows easily and if bars are merely laid in place they will be swept aside as though they were chips. In other words, the reinforcing material should be so supported during construction as to insure that it will occupy its designed position in the completed structure. Braces, blocks, suspenders, spacers, ties, etc., should be used in ample number to make certain of this feature. All temporary fastenings should be removed as fast as the concreting reaches them, in order to prevent any unsightly, dangerous or deteriorating matter remaining in the concrete. Wherever practicable all the reinforcement should be put in place in the forms and securely fastened in correct positions by wiring or otherwise before the placing of the concrete is begun.

All wiring, straps, braces and templates required for the proper holding of the reinforcement in place should be furnished by the contractor in a manner entirely satisfactory to the engineer.

Wiring Reinforcement.—The wiring of reinforcement at intersections should be done carefully and strongly, using No. 16 or No. 18 B. & S. gauge soft black wire, such as stove pipe wire. Reinforcing bars should be wired together at laps and intersections, where directed. The wire should be cut into lengths of about 8 in. and preferably two pieces used at intersections.

Tagging Reinforcing Bars.—When the bars are cut and bent to proper shape, each individual bar in every beam and girder, or group of bars in columns, slabs, walls, footings, etc., should be tagged with a cloth tag and wired securely to the bars (for beams and girders), or each bundle of bars, and marked with the proper number of the structural member, and the tags should be left on after the bars are placed in proper position in the forms. The engineer or his inspector should carefully examine the bars after they have been placed, personally remove the tags, after which the concrete may be placed.

Placing Concrete.—The contractor should be required to take the greatest care in the erection of the reinforcement, keeping a constant eye on it at the point where the concrete is being placed, to see that all the bars are in the proper location. Concrete should not be deposited in any portion of the work until all the reinforcement for that section of work is in position and has been checked over to see that it agrees with the drawings. It is cheaper to delay the work than to cut out work already done. See that the bars are clean when installed in place, ready for concrete. Care must be taken not to knock the bars out of position while concreting. In this connection, see Art. 25.

The steel work must be kept sufficiently ahead of the concrete work to give ample time for inspection. In fact, all steel must be placed ahead of the concrete except where instructions are given to the contrary (in very exceptional cases only). In such cases, the bars must be put in at the point designated by the engineer or his drawings, and they must be bedded solidly in the concrete, and all parts of the bar must have contact and adhesion with the concrete.

No concrete must be placed until the inspector has satisfied himself, by personal inspection, that the sizes and amount of reinforcement for each member designated upon the drawings is placed in position correctly. This inspection must be made immediately before the concrete is placed.

Protection of Reinforcement.—After placing steel reinforcement in position, if concreting be interrupted for any considerable length of time, the steel should be protected with canvas or tarred paper or other satisfactory covering. Ends of metal that are to be left projecting for a considerable time should be painted a heavy coat of neat cement wash or grout to protect them from corrosion.

COLUMN REINFORCEMENT

Assembling Stayed Column Reinforcement.—All reinforcing bars for columns should be assembled together before being placed in the forms. Stays should be securely tied to each of the upright bars. No free ends of stays should be bent out of line of the stays, and the stays should be tight and regularly spaced. All stays should preferably have both ends turned and clinched around the vertical steel. Wire ties or stays holding the vertical bars should be taut, and should always fit exactly. Figure 18 shows correct and incorrect way of fastening ties or stays. The vertical spacing of the stays should be exact and according to the engineer's plans. This spacing is generally 12 in. on centers for ¼-in. stays. Wire ties or stays must be

Fig. 18. Correct and Incorrect Method of Tying Column Bars.

fastened together as shown on drawings. Stays for columns may be welded to develop the full strength of the section.

Hooped Column Reinforcement.—While there are several types of reinforced concrete construction, almost the only *assembled units* on the market are those for hooped columns, since the other types of column reinforcement (stayed columns as described above) are assembled in the field from loose bars. The main points of difference in *hooped column reinforcement* are the methods of fastening (see Fig. 19). The hoops may be arranged either as a spiral or as annular rings, and the hooping material may be either flat band steel or wires. The hooped columns of individual steel hoops are horizontally spaced upon vertical spacing members at regular distances, usually two or three inches. For small-size hooping the spacing verticals generally consist of flat steel strips with projections arranged to clinch both top and bottom of each band, thus constituting a secure and rigid fasten-

ing. For heavy hooping the spacing verticals may be of structural steel punched for staple fastenings. The longitudinal reinforcement may be part of the hooping unit or separate bars may be inserted.

The hooping may consist of varying sizes of wire ranging from ¼ up to ⅜ of an inch, coiled in the form of a helix, spaced from 1 in. to 3 in., and in lengths as required. The spacing bar is generally provided with a projecting rib, which is sheared from the main section to form projecting fins. The spacing of these fins corresponds to the required pitch of the spirals and when bent around the spacing bars, spaces and holds the spiral in exact position. Wire hooping is rolled at the shops to various diameters, and the proper number of coils in a continuous piece can be supplied when the pitch and story-heights are known.

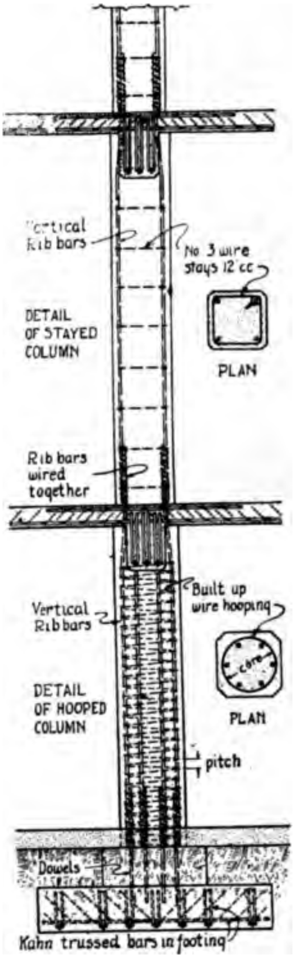

Fig. 19.
Hooped Column Reinforcement.

Fabricating Column Spirals.—Spiral reinforcement for columns should preferably be shop fabricated on machines designed especially for that purpose. In making spirals two processes are involved: First, bending the steel, which is usually in the form of wire, to the required diameter; second, spacing the coils to the required pitch, and fastening them so rigidly to small longitudinal spacing bars that this pitch will not be disturbed in handling. The first process is accomplished more economically by machine, the second usually by hand.

For fabricating spirals on the job, a simple wooden reel may be employed, the requisites of this reel being that it should be rigid, adjustable for different diameters, and collapsible to allow the finished spiral to be easily slipped off. Particular care should be taken in forming the spirals for columns and in properly fastening them to the longitudinal spacing bars so that the pitch of the spiral will be accurately maintained. See that the fins on the spacing bars are carefully bent around the wire spiral, thus holding it rigidly in position. Spirals should be bent to a true curve. No splices should be allowed in the spirals, except at floor levels.

Sometimes spirally wound flat band hooping is used. Staples are crimped into the grooves on one side of each spacing bar (which generally serves as the vertical reinforcement for the column), in-

stead of fins as mentioned above, at proper intervals. The necessary number of reinforcing bars are assembled on a circular form, with the stapled sides outward; the hooping is then wound around them, so that it passes between the outwardly projecting legs of each staple; these are then bent down so as to closely enclose the hooping and hold it rigidly in position. The reinforcement of the column is thus assembled as a unit; the form made for assembling is made to collapse, and the assembled reinforcement taken off and set up in position.

Assembling Spiral Reinforcement.—After the spiral hooping has been properly fabricated as described above or has been shop fabricated, the longitudinal reinforcing bars should be placed inside the core and wired to the shell at four or more points, so that the two sets of reinforcement form a strong network. In other words, the column bars should be rigidly wired to the coils at frequent intervals, so that they retain their desired spacing in handling and concreting. The entire reinforcement for the column is then placed as a unit in the work. After placing the column spirals and properly tying the longitudinal bars into their proper positions, no more reinforcement should be erected until the column forms have been filled with concrete (see page 306).

Spacing Column Bars.—Templates should be used at bottom and top of column to insure accurate spacing of bars. This is necessary to insure that the bars of successive columns will fit when spliced. Where bars are bent at top to form connections with column above, another template should be used to be sure that the connections will fit.

Splicing Column Bars.—Splices are the critical parts of column reinforcement and should be watched with care. Column bars may be spliced as follows:

(a) In a butt joint the ends should be square, the bearing uniform, and the joint held to line by sleeves of splice bars.

(b) If lap joints are allowed, the wire wrappings, cable splices, etc., should be made taut and secure.

Large bars should be properly butted and spliced. Small bars may be lap jointed. Various styles of column splices are shown by Fig. 20.

Butt Joints for Column Bars.—Column bars should have full perfect bearing at each joint, and such joints should occur at floors or other points of lateral support and a tight fitting pipe sleeve or wired splice bars should be provided at all joints of column bars. A good way of splicing column bars is to use an extra splice bar wired to both the upper and lower bars, holding them directly in line and in contact with each other. If extra splice bars are called for they should never be omitted. Column bars which do not fall exactly under those of the story above should be heated and carefully bent before being hooped or stayed together, so as to be perfectly in line vertically.

Lap Joints for Column Bars.—Lower column bars should be carried into the upper column sufficiently to develop the full strength

of the upper bars and should be wired to the latter with No. 10 wire hoops having 1 in. pitch.

Structural Shapes.—Where structural shapes of more than 2 in. width are used, they should be wired (hooped) with No. 10 annealed wire, 2 in. pitch.

Bearing Plates.—At foundations, steel bearing plates should be provided for large bars or structural shapes. No reinforcement should be put into the column forms until the bearing plates at the bottom are properly grouted in place. These plates are generally placed about $\frac{3}{4}$ in. below the top of footings.

Placing Column Reinforcement.—When the reinforcement is built up inside the form one side is left open for the work; ordinarily the

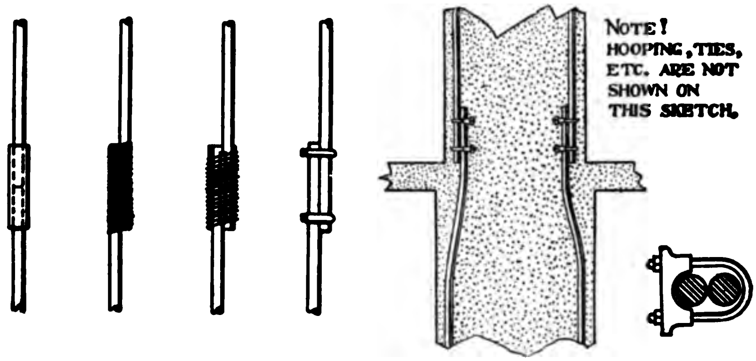

Fig. 20. Splicing Column Bars.

column reinforcement will be fabricated into unit frames as described above, then an opening in the form at the bottom to permit splicing will suffice. The reinforcing frame for the column should be placed plumb, concentric with that of the column below, and braced in two directions. No part of the steel should touch the walls of the form and the space between the steel and the form should be uniform. The vertical steel should be uniformly $1\frac{1}{2}$ in. to 2 in. from the forms. Column bars should be held in a sufficiently rigid manner to maintain their accurate positions. Bars in columns are easily miss-set, with disastrous results. Owing to the large amount of steel at the column splice, especial care must be taken in its placing. This is the most important part of the column, and the strength of the structure depends to a large extent upon the correct placing of the steel. It makes a material difference as to the length of the splice allowed in such columns. In one instance, an enterprising laborer, observing the bar in a column projecting out of the concrete in the column of a several-story building, seized a sledge hammer and drove them down flush with the surface of the concrete. The remedy for all this is inspection; most careful inspection.

Bending Column Bars.—Before placing column reinforcement, the contractor should make certain that all bends required in same, at

points where they extend into smaller columns on floors above, are made.

Column Footings.—The steel reinforcement of column footings should never be painted, even if the footings are to be placed in damp situations, because coating the bars will partly destroy the bond that it is necessary to maintain between the concrete and the steel (see page 263); besides, the concrete is sufficient protection for the steel against any serious corrosion. In all instances, however, the steel bars should be cut off enough to allow the ends of the bars to be entirely protected.

In case of column footings, a 2-in., or sometimes 4-in., layer of concrete should be spread on the ground before the footing bars are placed. Each bar should be tied at two points by No. 16 wire. Dowels must not be overlooked.

BEAM AND SLAB REINFORCEMENT

Concrete Spacing Blocks.—Notched concrete spacing blocks composed of the best concrete may be used for beam, girder and slab reinforcement. The notches should be properly spaced so as to separate the bars from each other and from the sides of the forms, and the blocks should be of the proper thickness to hold the bars at the required height above the bottoms of the beams, girders and slabs. The use of spacers and separators are not only necessary from a construction standpoint, but also for prevention of damage by fire and rust. If separators are not used, the bars will surely be more or less displaced by the dumping of the concrete carts and during ramming.

Spacing Chairs.—Spacing chairs or heavy wire supports may be substituted for the concrete spacing blocks mentioned above. (See page 266.)

N-Shaped Saddles.—Saddles made of No. 20 gauge metal strips $3/4$ in. wide may be bent N-shape and nailed to forms and then the slab rods laid on the saddle and wired thereto.

Washers for Supporting Slab Bars.—Washers may be threaded over the system of bars lying next to the forms, so as to hold them off the forms, giving a space for the fireproofing of bars.

Bending Beam Reinforcement.—In bending the beam and girder bars, care must be taken that the depth of the bent bars is not

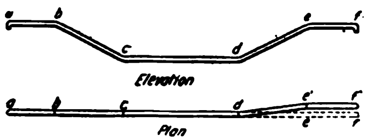

Fig. 21. Error in Bending Beam Bars.

greater than given in the drawings, as otherwise the bars might project above the concrete floor. The bends must be accurate in line and plane; the accompanying sketch, Fig. 21, shows the nature

of the error to be guarded against. The bends are not all in one plane *af*, but the one at *d* is twisted to one side *de′f′*.

Tagging Beam and Girder Bars.—When the bars are cut and bent to proper shape, each individual bar in every beam and girder should be tagged with a cloth tag, wired securely to the bars, and marked with the number of beam and girder, and the tags should be left on until after the bars have been inspected in the forms and permission given to remove them.

Marking Centering.—When the forms are ready for the steel, the contractor should go over the floors with the blueprints and a piece of crayon or keel and letter the beams and girders to correspond with the plans, in large figures on the decking beside the beams, and should specify the bars required, for example:

Beam B14.
  Two—7/8″ Rounds, Bent.
  Two— 1″ Rounds, Straight.

Beam and Girder Units.—In order to reduce inspection work on the job, the simplest system of steel work should be selected. The simplest system is essentially a built-up beam and girder system shipped to the job ready for placement. There are several forms of beam and girder reinforcement which are either in one piece or assembled together as one unit.

Placing and Fastening U-Bars or Stirrups.—Sufficient stirrups should be provided in beams and girders to take up with the bent bars all the diagonal shearing strains. All stirrups should be placed in the position shown on drawings, and should never be placed farther apart than the effective depth (preferably three-fourths of the depth) of the structural member, and must always pass under main tension bars. Care must be taken to properly space stirrups and to keep them in place during concreting. The placing of loose stirrups requires very careful supervision on the part of the inspector.

U-bars should be accurately bent, with, say, 6-in. wing resting on the form work. Under each wing should be placed one 1/4-in. or 3/16-in. rod, to which each U-bar should be wired, and to assist in holding up bent-up floor steel. Where no floor slab occurs on one side or two sides of a beam, bend wing of the U-bars into the beam, fastened to side of beam with staples.

Placing Beam Reinforcement.—Especial care must be taken in placing steel in beams and girders so to distribute and arrange the bars that each individual part may be incorporated within an individual part of the concrete. The stirrups should first be placed in all beam and girder forms as shown on drawings (and fastened as described above), then the straight bars, and afterwards the bent bars.

The bars should be placed symmetrical with the axis of the beam; the bars should be held the required height above the bottom of the beam (generally 1½ in.), and the proper space should be maintained between the reinforcement and the sides of the beam. Care must be taken to see that beam and girder reinforcement is so

steel scrapers or brushes, pickling in a weak solution of hydrochloric acid, or by some other equally efficient means of cleaning the metal, before being covered by the concrete.

Use of Pickling Bath.—Rusty or dirty steel, if permitted by the specifications, may be cleaned by pickling in a bath consisting of 1 part commercial sulphuric acid to 5 or 6 parts of water, or other proportions, depending upon the amount of rust on the bars. Bars must be washed thoroughly in clean water after the bath and before placing in the concrete. In other words, where the bars are pickled in acid they should be thoroughly washed afterwards so as to remove the acid before depositing the concrete. Any remaining traces of acid may be detected by tasting the water left on the surface of the bars.

Cleaning Forms.—No steel should be placed until the forms have been thoroughly cleaned and inspected. Forms must be cleaned of all dirt and shavings and care must be taken to prevent new dirt and shavings from coming into the forms. (See Art. 18.)

Assembling Reinforcement.—The steel reinforcement should be so assembled that the exact number, size, form, spacing and location of bars, stirrups, ties, spacers, etc., called for by the engineer's plans is adhered to in every member. Should any discrepancy be noted in regard to the reinforcement of similar members, it should be brought to the immediate attention of the engineer in charge of the work.

Carelessness in Placing Reinforcement.—The design of a concrete structure contemplates the placing of the steel reinforcement in exactly the position shown by the plans and cross-sections of the various members. The careful placing of bars is one of the most important features of reinforced concrete construction, and one which is too often neglected because of the expense of doing it right. The greatest element of danger exists in the misplacing of the reinforcement, leaving it out of the forms altogether, or in placing it so carelessly as not to have it near the position upon which the calculations were based. Carelessness frequently exists in not properly lapping the steel reinforcement at junctions.

It is the inspector's duty to insist upon the reinforcement being accurately placed, and any carelessness on the part of the contractor in this should be sufficient grounds for the engineer to require the removal of the work, and the replacing of it correctly. Haphazard and slovenly methods of placing steel reinforcement are unjustifiable and must give way to more scientific conditions. The displacement of the reinforcement, either by accident or design to facilitate the placing of the concrete, may cause the failure of the structure.

Results of Inaccuracy in Placing Reinforcement.—Steel reinforcement must be set accurately in place in accordance with the detailed drawings for that purpose. A great many workmen seem unable to appreciate the importance of exact, not approximate, placement of the steel. Results of not taking proper precautions to insure the exact, not approximate, position of the steel in the finished structure, are:

(1) Congestion of bars in bunches, not allowing proper amount

of concrete to encase each bar; crowding of a bar or bars to one side of the form, resulting in slight or no protection to the steel and insufficient bond.

(2) Position of one or more bars either too low or high, in the one case giving insufficient protection and bond, and in the other reducing the efficiency of the steel itself (see pages 277 and 280), since the closer to the neutral axis the bars may lie, the less they come into action. Designers are usually quite conservative in their allowance for protection of steel by fireproofing concrete below it, and the contractor better err on the safe side and take advantage of this allowance rather than to keep above same.

(3) Uneven bedding so that while one end may be all right the other may be far too high.

(4) Bars too far one way, falling short of one support and overlapping the other an unnecessary amount.

(5) Mistakes in amonnt and size of steel, as called for by the design, attended by even more serious results—unless steel is positioned before attempting to concrete it cannot be checked either in amount, correctness of sizes, or position.

Number of Bars.—The inspector should see that the exact number of bars, stirrups, ties, etc., called for by the engineer's plans, goes into every member. In other words, the amount of the reinforcing, that is, the number of bars used, should be frequently checked to see that the plans are followed. In a section having 50 bars, it is very easy for the contractor to leave out half a dozen.

Sizes of Bars.—The inspector should see that the sizes of bars used in any member correspond exactly to the engineer's plans. The wrong reinforcement may be used. It is an easy matter to make an error of $\frac{1}{8}$ in. in the selection of bars. This may mean a decrease of 25 to 50 per cent in strength. When made-up frames are used error is equally liable in their selection.

Form of Bars.—The form of each bar should be the exact form called for by the engineer's plans. Deformed bars should have a deformed cross-section, that is, the various cross-sections should be of different shape or their centers should not lie in the same axis.

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The clear spacing between parallel reinforcement in beams and girders should not be less than $1\frac{1}{4}$ ins. No reinforcing bars should be closer together than $2\frac{3}{4}$ diameters, center to center.

In spacing the bars, in slabs or columns, templates should be used to make certain that all connections will fit accurately.

Bearing at Ends of Bars.—Care must be taken to see that all bars have a sufficient bearing at ends or over supports. Failure to do this frequently results in difficulty and trouble.

Embedment of Reinforcement.—Steel reinforcement should be em-

steel scrapers or brushes, pickling in a weak solution of hydrochloric acid, or by some other equally efficient means of cleaning the metal, before being covered by the concrete.

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… chair should be bent to form flat feet and pre-
… e form boards when used to support floor re-
… ll and column reinforcement, the bending of the

bottom edge of the chair to form feet may be omitted, and for spiral hooping the slots for the spiral rods may be cut to pitch so that the chairs set straight with the vertical bars. The chief objection to metal spacers and separators is that they form a straight joint in the fireproofing and also conduct heat to the bars. (See page 274.)

Support of Metal Separators.—All metal separators used to keep the reinforcement at the right distance from the forms should rest on a piece of galvanized iron or else a rust spot will show on the under surface.

Supply of Supports.—Enough supports should be furnished to prevent sagging of the reinforcement.

Wooden Blocks.—Wooden blocks should not be used unless absolutely necessary for the reason that, remaining in the concrete as they are liable to do, a weak spot will be developed.

Bending Steel Bars.—All reinforcing bars must be bent before they are placed in position. Work should be so arranged that all bars of the same size and shape will be bent at the same time. This will avoid remeasuring, resetting of templates, etc. The bending of all bars should be done in such a manner that they will not break or crack at the end. The bending force should be applied gradually and not with a jerk. In other words, bending must be done with great care, so that no appreciable strength is lost thereby, being done with large radii in the curves so that no injury results. While the difficulties incidental to bending heavy steel bars to sharp corners usually prevent such practice, it is different with the U-bars used for stirrups and other light steel, and many half broken bars of the lighter sections have without doubt found their way into important work.

Bending must be done with absolute accuracy in accordance with the dimensions and forms shown on the detail sheets for the various portions of the structure. The bends should be accurate in line and plane.

Reinforcing bars can usually be bent cold, but for sizes 1½ in. and upward some makes of bars require heating; this can be done by laying the bars side by side on the ground and arranging sticks and shavings on top of them in a strip 18 in. to 2 ft. wide across the portion where the bend is to be. If the bars are heated and blacksmith work is done, care must be exercised that the steel is not burned in the operation, otherwise it should be condemned. Warming up to a low cherry red should be the highest heat permitted. In other words, only moderate heating should be allowed, which in most cases is all that is required. All ordinary bending, however, should preferably be done cold. It is very important, especially in bending large bars, that the bending force be applied gradually and evenly and not with a jerk.

All bends and angles should be carefully examined for cracks before placing the bars in position. Cracked bars must be replaced. When any bars are broken they must be replaced.

Bar Benders.—Several devices are on the market which facilitate the bending and shaping of reinforcing bars. Bending machines

bedded to a depth of at least 1 in. from any surface, unless otherwise shown on the detailed drawings or stated in the specifications. Care must be taken to keep all bars at such distance as the engineer directs from the nearest exposed face.

Thickness of Concrete Covering.—The minimum exposed concrete covering of all faces for steel reinforcement used in building construction is generally as follows: $\frac{3}{4}$ in. for slabs; $1\frac{1}{4}$ in. for beams and girders; $1\frac{1}{2}$ in. for columns and walls, and 2 in. for foundations.

Placing Reinforcement in Proper Position.—The most imperative duty of the inspector is to see that no detail of the engineer's design of reinforcement is varied from in placing the reinforcement in the structure. The contractor must be required to follow very closely the plans or the instructions of the engineer in the placing of the reinforcing material, both as to size, spacing and placing relatively to the surfaces; and where no measurements are given on the drawings the contractor must be required to follow the instructions given by the engineer. The steel reinforcement must be placed the proper distance from the bottom and sides of the forms and in the position required in the finished structure, and each piece or member so firmly fixed as to positively prevent any subsequent displacement when concrete is being poured.

Heavy reinforcement should be placed within the forms before the form tie-rods are placed, as these tie-rods frequently interfere with the placing of heavy reinforcement.

It is absolutely essential that the steel be placed in proper position so that the line and level of all bars and of the reinforcement as a whole are accurate. If either the number, size or spacing of the reinforcements is varied from, the strength of the concrete member will not be what it was designed to be and injury results. In other words, the inspector shall insist that the reinforcing steel be properly positioned as called for by the design, and suitably secured and carefully checked before attempting to pour concrete. In no case should a greater variation in height than $\frac{1}{2}$ in. be allowed, or in other dimensions of over $\frac{3}{4}$ in. No steel must appear on the surface of the work.

The proper reinforcement of the members is of the highest importance and nothing can be permitted to interfere with it.

Metal clips or cement blocks should be used for keeping the steel bars the proper distance away from each other or from the face of the form. The ordinary way is to have a laborer raise the bars from the forms with his shovel-blade or a hook made for the purpose, but such methods rarely result in satisfactory work, as there is no gauge to determine the final position of the bars and if the concrete flows under them in too large a quantity their efficiency will be impaired.

Spacing "Chairs."—Spacing "chairs" and clips for bar reinforcement should be made of a heavy weight and a good quality of sheet steel. They should have ample strength against crushing down under such loads as are likely to come on the reinforcement. The bottom edges of the chair should be bent to form flat feet and prevent cutting into the form boards when used to support floor reinforcement. For wall and column reinforcement, the bending of the

bottom edge of the chair to form feet may be omitted, and for spiral hooping the slots for the spiral rods may be cut to pitch so that the chairs set straight with the vertical bars. The chief objection to metal spacers and separators is that they form a straight joint in the fireproofing and also conduct heat to the bars. (See page 274.)

Support of Metal Separators.—All metal separators used to keep the reinforcement at the right distance from the forms should rest on a piece of galvanized iron or else a rust spot will show on the under surface.

Supply of Supports.—Enough supports should be furnished to prevent sagging of the reinforcement.

Wooden Blocks.—Wooden blocks should not be used unless absolutely necessary for the reason that, remaining in the concrete as they are liable to do, a weak spot will be developed.

Bending Steel Bars.—All reinforcing bars must be bent before they are placed in position. Work should be so arranged that all bars of the same size and shape will be bent at the same time. This will avoid remeasuring, resetting of templates, etc. The bending of all bars should be done in such a manner that they will not break or crack at the end. The bending force should be applied gradually and not with a jerk. In other words, bending must be done with great care, so that no appreciable strength is lost thereby, being done with large radii in the curves so that no injury results. While the difficulties incidental to bending heavy steel bars to sharp corners usually prevent such practice, it is different with the U-bars used for stirrups and other light steel, and many half broken bars of the lighter sections have without doubt found their way into important work.

Bending must be done with absolute accuracy in accordance with the dimensions and forms shown on the detail sheets for the various portions of the structure. The bends should be accurate in line and plane.

Reinforcing bars can usually be bent cold, but for sizes 1½ in. and upward some makes of bars require heating; this can be done by laying the bars side by side on the ground and arranging sticks and shavings on top of them in a strip 18 in. to 2 ft. wide across the portion where the bend is to be. If the bars are heated and blacksmith work is done, care must be exercised that the steel is not burned in the operation, otherwise it should be condemned. Warming up to a low cherry red should be the highest heat permitted. In other words, only moderate heating should be allowed, which in most cases is all that is required. All ordinary bending, however, should preferably be done cold. It is very important, especially in bending large bars, that the bending force be applied gradually and evenly and not with a jerk.

All bends and angles should be carefully examined for cracks before placing the bars in position. Cracked bars must be replaced. When any bars are broken they must be replaced.

Bar Benders.—Several devices are on the market which facilitate the bending and shaping of reinforcing bars. Bending machines

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should be required to bend any kind of a steel bar up to $1\frac{1}{4}$ in. in diameter to any angle required.

A simple cast iron block for bending bars may be made of a block of metal with a longitudinal groove cut in it. The block is attached rigidly in a horizontal position to a work bench, the bar to be bent is dropped in the slot, a piece of extra heavy pipe is then slipped over the end of the bar, and a couple of men can bend it to the required angle. A bending block may also be made of an iron plate with two angles riveted to it back to back to form a slot. Stirrups when bent by hand may be bent on such a plate, the angles, of course, being small and only far enough apart to admit of the size used for stirrups.

Splicing or Lapping of Bars.—When the reinforcing bars required are very long the individual bars must be spliced. The lap should be great enough to develop the strength of the steel, or at least 40 diameters. Contractors are wont to ignore this provision of the specifications and reduce the lap to about 20 diameters, thus effecting a saving in steel. The splicing of bars should be done exactly according to the engineer's plans. No splices whatever should be permitted except at points shown on plans. Various forms of splices are in use and if not definitely instructed by the plans and specifications the inspector should learn from the engineer what form or forms will be acceptable (see Fig. 20).

Where extra splice bars are called for, care must be used to see that they are not omitted.

The length of lap required for splicing of reinforcing bars in tension should be determined on the basis of the safe bond stress and the stress in the bar at the point of splice; or a connection should be made between the bars of sufficient strength to carry the stress. Splices at point of maximum stress should be avoided.

Headers.—In all work built between forms, in which the horizontal bars run farther than the lengths of the forms for that particular section of work, the headers against which work ends should be perforated at the proper places and the bars should project through the same for a minimum distance equal to the least lap allowed for the size of the bar, and all of different lengths, so that in no place will laps occur nearer to each other than 2 ft. in adjoining bars in the same plane. (See page 280.)

Welding of Bars.—No welding of reinforcement except in column hoops should be permitted without special permission from the engineer. Welding should, however, be avoided if possible, and is permissible at such points only where the stress is rather insignificant.

Protruding Ends of Bars.—The ends of bars which are left protruding for splicing should be, if they are likely not to be connected up for some little time, painted with cement paint to diminish rusting and guard against being bent or loosened. Throughout the work care must be exercised to prevent disturbing bars, portions of which are embedded in fresh concrete, otherwise the adhesion between the bar and the concrete will be broken.

Fastening Reinforcement.—All reinforcement should be securely

fastened to preserve spacing, location, alignment, etc. Where a wet gravel concrete is used, the need of secure fastening for the bars is particularly great. Such a concrete flows easily and if bars are merely laid in place they will be swept aside as though they were chips. In other words, the reinforcing material should be so supported during construction as to insure that it will occupy its designed position in the completed structure. Braces, blocks, suspenders, spacers, ties, etc., should be used in ample number to make certain of this feature. All temporary fastenings should be removed as fast as the concreting reaches them, in order to prevent any unsightly, dangerous or deteriorating matter remaining in the concrete. Wherever practicable all the reinforcement should be put in place in the forms and securely fastened in correct positions by wiring or otherwise before the placing of the concrete is begun.

All wiring, straps, braces and templates required for the proper holding of the reinforcement in place should be furnished by the contractor in a manner entirely satisfactory to the engineer.

Wiring Reinforcement.—The wiring of reinforcement at intersections should be done carefully and strongly, using No. 16 or No. 18 B. & S. gauge soft black wire, such as stove pipe wire. Reinforcing bars should be wired together at laps and intersections, where directed. The wire should be cut into lengths of about 8 in. and preferably two pieces used at intersections.

Tagging Reinforcing Bars.—When the bars are cut and bent to proper shape, each individual bar in every beam and girder, or group of bars in columns, slabs, walls, footings, etc., should be tagged with a cloth tag and wired securely to the bars (for beams and girders), or each bundle of bars, and marked with the proper number of the structural member, and the tags should be left on after the bars are placed in proper position in the forms. The engineer or his inspector should carefully examine the bars after they have been placed, personally remove the tags, after which the concrete may be placed.

Placing Concrete.—The contractor should be required to take the greatest care in the erection of the reinforcement, keeping a constant eye on it at the point where the concrete is being placed, to see that all the bars are in the proper location. Concrete should not be deposited in any portion of the work until all the reinforcement for that section of work is in position and has been checked over to see that it agrees with the drawings. It is cheaper to delay the work than to cut out work already done. See that the bars are clean when installed in place, ready for concrete. Care must be taken not to knock the bars out of position while concreting. In this connection, see Art. 25.

The steel work must be kept sufficiently ahead of the concrete work to give ample time for inspection. In fact, all steel must be placed ahead of the concrete except where instructions are given to the contrary (in very exceptional cases only). In such cases, the bars must be put in at the point designated by the engineer or his drawings, and they must be bedded solidly in the concrete, and all parts of the bar must have contact and adhesion with the concrete.

done. For walls and heavy work, retempered concrete ought not to be objectionable when used in limited quantities. In other words, the uniformity of the work should not be disturbed by using an occasional batch of concrete that has received a different treatment from the rest of the work. The inspector, of course, will be governed by the engineer's instructions as regards the use of retempered concrete. The author would recommend that in reinforced concrete construction its use be entirely avoided.

Concreting at Night.—The placing of reinforced concrete work at night is fraught with considerable danger and should be avoided whenever possible. It is sometimes necessary, however, to continue concreting into the night when work of importance must not be stopped or broken off. When such work as this comes under the charge of the inspector, he must depend on the illumination available and take every precaution to safeguard the misplacing of steel in the forms and the danger of fire from the lights. The inspector must be constantly on the job.

Adequate lights must be provided at the mixing machine and throughout the area where the concrete is to be placed. No night work should be permitted unless suitable arrangements are made for the lighting of the work. It has been the author's practice to prohibit finished concrete work at night, although if the contractor would provide a sufficient number of arc lights there is no reason why the finished work can not be so executed.

During the progress of night work extra precautions must be taken to see that the material, and especially the cement, is properly supplied to the mixer. It is also necessary to be extremely careful that the work is carried on in exact accordance with the specifications; and the inspector cannot be any too careful in this respect. Night work should be carried on with as small a gang as will insure the placing of fresh concrete before that beneath it has set.

No concrete should be placed at night unless upon the approval of the engineer.

Art. 25. Placing, Puddling and Ramming Concrete

The different types of construction require different consistencies of concrete (see page 187), and the method of depositing varies accordingly. Depositing concrete after mixing is a very important step in concrete work, and to secure the best results, the following points should be thoroughly observed.

GENERAL REQUIREMENTS

Handling Concrete.—Concrete, after the addition of water to the mix, should be handled rapidly and in as small masses as is practicable. The amount of concrete that should be placed at once depends upon the kind of construction and the kind of concrete. Comparatively dry mixtures, which in general should only be used in massive, unreinforced work, may be carried in ½ cu. yd. or

1 cu. yd. buckets, handled with a derrick. If large quantities of concrete are placed at a time or in one place in reinforced concrete work, it may cause springing of the forms, or it may bend or displace the reinforcing bars or any rods that are used to brace the forms.

No concrete should be wheeled over 175 ft. from mixer to point where it is to be deposited, unless absolutely unavoidable. Too long a trip for a wheelbarrow or cart must be avoided, unless proper precautions are taken, because the liquid separates from the mass and, if in a leaky wheelbarrow, is lost; or if in a tight iron wheelbarrow or in carts, the workmen often empty the "slush," which is mostly cement, elsewhere than where it ought to go. In handling and transporting concrete, it is essential to prevent the separation of the stones from the mortar. If long trips are unavoidable, the concrete should be dumped on a small platform, preferably of sheet iron, and remixed by turning over several times, and then shoveled to its proper place. No wheeling should be allowed on the centering or green concrete. Running wheelbarrows directly across reinforcing rods must not be allowed. The wheelbarrows must not be filled so full as to permit mortar to slop out. Do not try to save labor when depositing concrete, as this has spoilt many an otherwise good job of concrete.

The concrete should be handled quickly and brought to the points of placing by hoists, derricks, concrete buggies or wheelbarrows (see Art. 23). If the concrete is to be hauled by laborers in wheelbarrows or carts, the inspector should see that the line of men going to the work and that of the men going back to the mixing place for more concrete do not get in each other's way, and that there are no delays at either end of the line to keep them waiting.

When concrete is properly made, the whole mass becomes one stone when it has set, and it is therefore very important that the placing of the concrete should be continuous. The contractor may at times be required to complete the section of work then going on without stopping, even if working overtime is resorted to. It is sometimes of great importance that no stop be made in placing the concrete in any portion of the work until the depth or thickness called for is in place. This is particularly true of reinforced work. In continuous work the inspector should see that the placing is conducted in such order as will prevent the concrete first placed from becoming set before the remainder is placed. The materials may be of the best and mixed in the proper proportions and manner, but if not properly put into place the result will be a bad job of concrete.

After concrete is taken from the mixer or the mixing platform it should be placed as soon as possible in the forms, as any disturbance of the mass after the cement has begun to set detracts from the ultimate strength. As a rule, the sooner it is placed, the better. Rapidity of execution where quick-setting cement is used is a point which must be carefully attended to. Some cements attain their initial set in about half an hour after being wet. A slow-setting cement should be used when a long time is likely to occur between mixing and final placing. It must always be remembered

that the hardening of concrete is not a "drying-out process," as some are apt to suppose, but is a chemical action caused by the addition of water to the cement. The concrete takes its "initial set" in a short time, and therefore should be deposited in place as quickly after mixing as possible. (See page 358.)

Concrete should be kept in motion until deposited in place. Concrete which has been allowed to stand, or has been transported in buckets or cars, has a tendency to unmix, and consequently is harder to work. The mortar adheres to the bottoms and sides of such receptacles, and considerable time and labor are lost in cleaning them out. If concrete stiffens in wheelbarrows, carts, or in the mixer, it indicates that the cement has a flash set, and it should not be used. In other words, the concrete must be deposited in the forms before it stiffens perceptibly; concrete held longer than that time in either the receiving hopper or the wheelbarrows should be wasted. If cement with a flash set has been used inadvertently the concrete must be soaked with water until it hardens.

Concrete may be handled and placed in any way best suited to the nature of the work, provided the materials do not separate in placing. Excess of water, causing materials to separate, must be avoided. In some work which was described to the author lately, the cement was found on top and the stone at the bottom of the conveying car, the ingredients being entirely separated by the time the bucket arrived at the dumping platform. The ingredients had been carefully mixed before reaching the car, but it was necessary to dump the concrete and remix by hand before it could be deposited. Of course the mixing might just as well have been done once for all at the dumping platform.

Dumping Concrete.—Concrete may be dumped from wheelbarrows or carts, or shoveled directly into place. Some men dump the concrete directly from wheelbarrows or carts into the structure. If the wall is a thick one, or if it is a large pier on a broad surface, like a sidewalk or floor (see Art. 51), this is all right. Should the wall, however, be thin, or be a column or narrow structure, the best way is to take the concrete in shovels from the wheelbarrows and throw it into place.

In depositing concrete in place, care must be taken not to undo the work of mixing. The concrete should be dumped as nearly as possible in the place it is to occupy in the work. Concrete must either be dumped slowly or shoveled out, and must not be dropped from too great a height or thrown from too great a distance when being placed upon the work; otherwise air will be trapped and the resulting concrete will not be uniform. Even tamping will not remove this lack of uniformity. The method formerly advocated, of dumping concrete from a height of three or four yards, is now discountenanced, for the reason that the larger stones in falling become separated from the mortar and smaller stones, and the concrete is not, therefore, homogeneous and uniform. It should not be dropped farther than 6 ft. The contractor should be required to

furnish suitable appliances, when necessary, to deposit concrete without allowing it an excessive free fall.

Concrete should be so deposited as not to injure the forms nor the concrete already placed. Do not allow concrete to be deposited in large masses, as from large buckets, except under the most favorable circumstances. Masses of entrapped water, and even air, have been found to have formed large voids in the concrete work. In narrow forms only small quantities should be dumped at a time.

Great care must be used in dropping the concrete. If the concrete is allowed to fall freely a distance of several feet, or to slide down an inclined plane, it will be likely to fall in a cone-shaped pile and separate the stone from the mortar, which will pile up, the result being a layer of broken stone followed by a layer of mortar. The broken stone or gravel will roll down the outside of the cone-shaped pile. This action is especially bad in concrete that is mixed rather dry. The inspector must insist upon the concrete being deposited in such a manner that there will be no separation of coarse from fine material. If this separation cannot be avoided by some other method of dumping, then care must be taken to remix the concrete.

There is one method by which the concrete may be deposited by gravity without causing a separation of its component parts. This consists in allowing the concrete to slide down a metal tube or enclosed trough, but the tube must be kept continuously full, the concrete being allowed to run out at the bottom only as fast as it is filled in at the top (see page 373). This method, however, is only applicable where the mixing is continuous, as in the case of machine mixers. (See also Art. 35.)

In large work, when there is a considerable drop from the place of mixing to the place of deposit, the concrete should generally be lowered in a bucket. Concrete dumped from large buckets should be lowered as near to the concrete as practicable, particularly when deposited on concrete which is not older than 48 hours, so that the bond between adjacent layers will not be broken. Buckets should just clear the work when discharged, for if the concrete is allowed to drop, it is liable to jar the forms and displace the reinforcement and at the same time produce separation of the stone from the mortar. Buckets should not leak and spill concrete over the work.

Wheelbarrows must not strike the floor in dumping.

If a receptacle is used to convey the concrete, it should be taken out of the receptacle in the order in which it is put in. This is unavoidable, however, when drop-bottom buckets are used for depositing concrete under water. It would be preferable to turn the bucket over and dump out its contents.

Pouring Wet Concrete.—Wet or liquid concrete must be deposited so that it will not flow along the forms or sweep the reinforcement out of place. Concrete should be poured in the most approved manner. That is to say, wet or liquid concrete should be so deposited as to maintain a nearly level top surface, and so avoid flowing along the forms. Concrete should be poured at several points over the area to be filled, so as to reduce flowing and spreading to a minimum.

When concrete is poured in at the end of a form and permitted to run down a slope, there is bound to be a separation of materials, the large pieces freeing themselves from the mortar and running ahead of it, the slow-moving mortar generally setting before it gets an opportunity to cover the fast-running aggregates, thus making porous places in the mass. Care must be taken in pouring the concrete in the narrow spaces of the forms so that stone pockets will not be formed.

Protecting Finished Work.—In depositing concrete, the inspector should be diligent to watch that none of the liquid cement, which is apt to leak through the joints in the forms, runs down the face of any completed brick or stone work, as it is almost an impossibility to prevent permanent staining of walls should the cement drippings be permitted to harden on the walls. If, by accident, the cement should run down the face of a finished wall, the drippings should be at once scrubbed off with a copious supply of water before the cement starts to set. Vigilance on the part of the inspector in this matter will save much annoyance later in getting the work properly cleaned. Care should be taken that the liquid cement does not enter the holes of sockets, etc. (See pages 289 and 337.)

Time of Placing Concrete.—The time elapsing between mixing and pouring the concrete must be well within the time-set of the cement. As a rule, the elapsed time should not exceed 30 to 60 minutes between wetting the cement and placing finally the batch of concrete. Generally concrete should be placed in less than one-half (½) hour after mixing. Some specifications restrict it to 10 minutes. The inspector, however, should be guided by tests in establishing a limit beyond which any concrete once mixed shall not be used in the work. The concrete takes its "initial set" in a short time, and therefore should be deposited in place as quickly after mixing as possible. Concrete mixed for over one hour shall not be allowed in the work.

Rehandling Concrete.—Concrete should be so placed as to avoid an unnecessary rehandling within the forms, if possible to do so. In other words, the pouring should be done directly from the wheelbarrows, carts, or buckets if possible; dumping onto shoveling boards and shoveling makes an extra operation. Where shoveling boards are necessary, take care that they are placed close to the forms being filled, as it is wasteful of time to carry concrete in shovels, even for a half dozen paces.

Preventing Concrete from Setting Too Rapidly.—Care should be taken not to allow the first concrete placed to appreciably stiffen or set before the remaining concrete is placed. The remedy for this is to occasionally, or as often as is necessary, add a little more concrete to that already placed over all exposed surfaces.

Placing Concrete under Water.—No concrete should be laid in water except under the instructions of the engineer in charge of the work, and with special permission for each case. Depositing concrete under water is discussed in Art. 36. Concrete should never be placed in running water without protection from the washings thereof or

allowed to come in contact while being deposited, with contaminated water, oils or strong alkalis.

Order of Placing Concrete.—Concrete should be placed in the positions as directed by the engineer, and the order of placing must in all cases be as directed by the engineer.

Work Divided into Sections.—The work should be carried up in sections of convenient height and length, and the sections completed without intermission as far as practicable. In no case should work on a section stop within eighteen (18) inches of the top, or any face. (See Art. 26.)

Manipulation of Concrete (Compacting).—The concrete should be deposited in such a manner as will permit the most thorough compacting, such as can be obtained by working with a straight shovel or slicing tool kept moving up and down until all the ingredients have settled in their proper places by gravity and the surplus water has been forced to the surface by ramming, or otherwise compacted so as to make a dense and compact mass. The manner and extent of the compacting should be satisfactory to the engineer. All concrete should be either tamped or puddled whenever practicable. For dry and medium mixtures, thorough tamping is necessary in order to obtain a solid mass. A wet mixture, in place of being tamped, is spaded or stirred (puddled) by continuous working with a suitable tool. A dry mixture is spaded only around the edges of the mold, but otherwise tamped until a moisture appears on top of the concrete. Even with very wet mixtures pockets or voids may occur unless the mass is puddled. (See page 345.)

When placing the concrete there must always be one man detailed, or more if the engineer so orders, whose duty it will be to do tamping or puddling exclusively, following up the shovelers or dumpers as they place the concrete. In general, the methods should be such as to give a compact, dense and impervious concrete.

Notes should be made of any cracks that may appear in concrete due to forms expanding, contracting or settling. (See page 312.)

Placing Concrete in Layers.—Excepting in arch work (see page 316), concrete should be deposited in horizontal layers of uniform thickness. Care should be taken that the concrete is placed in even layers. Layers of concrete must not be tapered off in wedge-shaped solids, but should be built with square ends, temporary planking being placed at ends of partial layers, so that none will run out to a thin edge. In order to avoid horizontal joints it is necessary that each layer should be deposited before the "initial" set of the previously deposited layer, and should be left somewhat rough to insure bonding with the next layer above, and should be of such thickness that it can be incorporated with the one previously laid. The surface of the top layers should be leveled with a straight edge, or in any other suitable manner. No loose stones or porous places should be left on the surface of any layer, but such places must be filled with mortar, and the ramming repeated until wet mortar flushes to the surface. In other words, the layers should be kept, in general, as nearly horizontal as may be during the process of

placing, one layer being completed before another is started, and layers of concrete must not be run out to a thin edge. The layers should be carefully watched, particularly in dry weather, to keep them from drying out too fast, and sprinkled if necessary.

See that the workmen when leveling off the concrete as it is deposited do not scrape it with the point of the shovel, thus scraping a lot of the aggregate out of the mortar and depositing it with no mortar in one place. Have the work leveled by spading and shoveling the concrete from the high into the low places, taking mortar and aggregate at each shovelful.

Staggering Layers of Concrete.—Layers of concrete should not be tapered off, but be built with square ends, and when, from any cause, it becomes impracticable to complete a layer, a plank of convenient width should be secured to the form, against which the concrete should be rammed, thus making a vertical joint. Should it become necessary to start a second layer at once, it should stop short of the first plank at least 12 in., when a second plank should be secured in the same manner as the first, and the concrete rammed against it, the layers being carried up full thickness to the board, and left rough. The ends, where a full layer cannot be laid at the time, should be squared off in every case by vertical temporary planking.

Thickness of Layers of Concrete.—The thickness of layers depends upon the character of the work in hand. Opinions differ as to the thickness of layers in which concrete should be deposited. Some advocate thick layers, some thin ones. The inspector, of course, will be governed by the specifications or by the engineer's decision in the matter.

A mixture which does not quake in the wheelbarrow should be deposited in layers not over six (6) inches thick and thoroughly tamped. Concrete has been rammed in 3-in. layers, however, very seldom, because, whatever care may be taken, the joints between the layers are always a source of weakness. Layers thicker than 6 in. for dry concrete should not be attempted unless a large number of men are employed in mixing the concrete, as otherwise the depositing and ramming a greater thickness may take so long that the lowest portion may have begun to set before the men can finish the upper part, and this will cause a disturbance of the setting, and consequent weakness. The reason for comparatively thin layers in rammed work is so that the ramming will be effective. In special cases, where the concrete must be placed on steep slopes, a dry mixture in 4-in. layers should be used.

A quaking mixture may be deposited in layers 10 to 12 in. thick, and should be puddled with a square-pointed spade. Even thicker layers of wet concrete may be placed at once in mass work, if it can be done without leaving air pockets.

Puddling or Churning Wet Concrete.—If the concrete is mixed either dry or plastic, it should be compacted by ramming (see page 299); and if the concrete is wet it should be stirred, to allow the entrained air and surplus water to rise to the surface. The stirring or "puddling" may be done either by plunging a rod up and down

in it, or by men wearing rubber boots walking around in it. Puddling should be thoroughly done so as to work out air bubbles and pockets and bring the concrete into close contact with the reinforcing steel at every point. In reinforced concrete, where wet concretes must be employed, it is important that the concrete be poured in such way and in such amounts as not to cause air pockets to form. The same is true of any concrete that is to be impermeable (see Art. 47). Ramming is not essential in such concretes, as puddling is quite as effective as ramming, if properly done. In fact, if the concrete is of such consistency that it can be rammed it is unsuitable for reinforced concrete work. The object is to get all air and surplus water out of the mass, and a sharp continuous agitation is more effective than blows from a rammer.

The wet concrete should be thoroughly churned after it has been deposited in the forms. Forks, spades, or other suitable instruments should be used for this purpose. These implements should be small enough to enter well into the spaces between and around the reinforcing steel and make the concrete flow into the corners and along all faces of the walls. In concreting, strike the bars, in preference to the concrete between the bars, with the tampers. In other words, bars should be lightly tapped to assist the settlement of concrete under and around them, and must be entirely encased in concrete, care being taken to insure the coating of the reinforcing metal with mortar and the thorough compacting of the concrete around the bars. Care must be taken to avoid displacing the reinforcing steel. Care must also be taken to see that the bars are thoroughly embedded in the concrete. Do not allow a lot of the aggregate free from mortar to gather around the bar, but see that the mortar comes in contact with the bars over their entire surface and is packed solid. Jarring of bars must be carefully avoided when the concrete begins to set.

The inspector should insist upon the concrete being well spaded, for only by thoroughly spading can air bubbles be worked out. The stones should be carefully but judiciously spaded away from the face; too much and unskillful spading will permit an upward flow which will wash the cement from the concrete at the face. In other words, excessive puddling or churning is injurious; it drives the stones together and forces the sand and cement to the surface. Puddling of wet concrete should be performed to only a moderate extent, just sufficient to expel the air. With very wet concrete poured in mass work it is not unusual to tamp or puddle it, except at the face that is to be exposed, for the purpose of forcing some fine material to that face so that it will present a smooth surface when the forms are removed. Care must be taken, however, not to pry on the concrete so as to spring the forms. (See Art. 41.)

Tools for Puddling Concrete.—With wet concrete, the so-called rammer may be either a round wooden rod 2 in. in diameter or a piece of scantling having a 2x4-in. face at the lower end and rounded at the upper end for a handle. A good tool to use for puddling concrete is a spading fork, which is usually made the shape of a spade,

but with four or more prongs. In narrow forms, instead of a spade a hoe may be used, with the blade bent nearly in line with the handle, or a scantling sharpened to an edge is satisfactory (see page 385).

Obtaining Smooth Face for Exposed Surfaces by Spading.—Faces exposed to view may be made smooth by thrusting a square-pointed spade or a thin tool, like a sidewalk scraper, through the concrete close to the form to force back the larger stones and prevent stone "pockets." Care must be taken in removing the large stones or pebbles from the face to prevent an upward flow which will wash the cement from the concrete at the face. The finer mixture must be flushed against the forms. It is sometimes customary to specify that no separate facing and no plastering will be allowed, and when the forms are removed, a smooth surface, free from voids, will be required, and pointing of holes in the face must be reduced to a minimum by the above method. (See Art. 30.)

In the case of a dry mixture, "spading" must be done with greatest care by experienced hands to get uniform results. Such special rammers and forks should be used near the surface as may be required to give the desired finish. (See Art. 41, page 384.)

Obtaining Smooth Surfaces with Rich Mortar.—Smooth surfaces may be obtained by spreading a thin layer of rich mortar (1 part of cement to 2 or 3 parts of sand), about 1 in. thick, over a section of the area to be concreted ahead of the regular mixture. The thickness of mortar facings should not exceed $1\frac{1}{2}$ in., nor be less than $\frac{3}{4}$ in. Care must be taken to remove from the forms the dried mortar which splatters against them, in order to secure a perfect face.

Placing Mortar Facing and Backing Simultaneously.—It is sometimes customary to place the mortar facing and backing simultaneously in the same horizontal layers. In order to gauge the thickness of the mortar facing accurately, a light board or diaphragm of thin metal with convenient handles should be set on edge parallel to and (1 or $1\frac{1}{2}$ in.) from the front wall of the forms. (See page 387.) The facing material is deposited in the space between this board and the form. The concrete of the backing should then be deposited and spread against the back of this board, which may then be withdrawn and the whole mass thoroughly rammed so as to bond the mortar facing and backing by destroying the surface demarcation between them, but no stone must be forced nearer to the front wall of the form than $\frac{3}{4}$ in. Necessary deviations from this method may be adopted on the approval of the engineer. Care must be taken to remove from the forms the dried mortar which spatters against them, in order to secure a perfect face. (See Art. 41, page 386.)

By using the metal diaphragm or light board in the manner above described, the face of each layer may be made, exactly the right amount of mortar and the proper amount of the layer may be accurately determined. The intention is that the facing and the backing should be rammed and set together. In no case is one to be put in in advance of the other, so that either may set before the

other. The facing should show a smooth, dense surface, without pits or irregularities. This is most likely to be secured by thorough and systematic ramming. The facing mortar should be of the same composition as the mortar used in the concrete back of same.

In places where the above method cannot be used, as the under surface of arches, the same end should be attained by methods satisfactory to the engineer.

Refinishing Mortar Facing.—In no case should any work be finished by plastering mortar or concrete which has set; but should it become necessary at any time to refinish a surface which has set, it should be picked off so that at least 3 in. of mortar can be added, and the surface of the old concrete should be roughened and thoroughly wet before new material is added, such new material being mortar as specified for facing. (See Art. 30.)

Ramming (Sometimes Called Punning) of Concrete.—For some unaccountable reason, most of the older specifications specify that the concrete shall not be rammed or tamped after being put in place, and in order that it may be, to a certain extent, solidified, it was specified that it should be dumped in place from a certain height. Nothing could have been more erroneous than such ideas. The concrete should not by any means be allowed to fall a considerable height. Such a fall tends to separate the large pieces from the smaller, and thus results in a lack of uniformity in the concrete. The concrete should be put in place with care, and not allowed to fall more than six (6) feet if possible. (See page 305.)

In placing dry concrete in layers, see that the layers are of the required thickness (see page 296), evenly spread and properly rammed. Each layer must be thoroughly rammed and consolidated so that no void spaces are left. The advantage of suitable ramming is obvious. It compresses the concrete, rendering it more solid and free from voids, and squeezes out all superfluous water. Ramming, when properly done, consolidates the mass about 5 or 6 per cent, rendering it less porous, and very materially stronger (nearly fifty per cent). The inspector must insist upon the thorough ramming and compacting of all dry concrete, as the value of the work largely depends upon the completeness with which this highly important part of the work is done. Too severe ramming, however, when the concrete is dry, is dangerous, as it will force the larger stone to the bottom, and, if the ramming is continued too long, the setting will be delayed and the strength permanently impaired.

The amount of ramming which can be done will depend upon the amount of water used in mixing. If too much water has been used in mixing, it will be impossible to compact the concrete by ramming. In fact, very wet concrete cannot be rammed at all. Even with a small amount of moisture a thin skim of water will appear on the top while tamping; this indicates a sufficient degree of compactness. If too much water is present the top will be flooded with a half inch or more of water mixed with pure cement, which will be forced up with the water, or a more or less semi-fluid paste will form on top. This will generally be accompanied with a spongi-

ness and a springing or wave-like motion of the concrete mass. This indicates that the concrete is too wet; also, that much of the cement has been brought to the surface, thereby reducing the strength of the concrete; and, furthermore, that the stones have been driven in too great proportion to the bottom. This will always occur in soft concretes even when not excessively wet, if the ramming be too heavy and long continued. With the concrete of the proper consistency, the author has found that a rammer not too heavy to be handled by one man will sufficiently compact the concrete.

The ramming must be completed as the work progresses. In no case should concrete be permitted to remain in the work if it has begun to set before the ramming is completed. The ramming should be done quickly in order to avoid the possibility of layers setting before completing them, but the tamping must be done thoroughly and not slighted. Concrete made with a quick-setting cement should be rammed very little, if at all. With such cement, there is a likelihood of the ramming being continued until the cement has begun to set, and the result will be a loss of strength. The quaking of concrete in tamping indicates that it is too wet.

The concrete should be carefully compacted around the steel reinforcement. It is necessary to tamp concrete very carefully. If not properly tamped, the shrinkage which occurs as the concrete settles drops the adjacent layers away from the reinforcement. This often forms a plane of cleavage at the reinforcement, so that the layer designed to afford adhesion and to give fire protection has been known to fall away of its own accord.

The bottoms of tamping tools should be kept clear of hardened mortar so as to pack the concrete with flat surfaces. No mortar that has been prepared for the purpose of forming a new batch of concrete should be taken to plaster any rough or improperly tamped places that may appear in the work, as ramming or tamping should be the only means employed to obtain a smooth and regular surface. There are two tricks sometimes employed to make it appear that this condition has been fulfilled. One is to scrape off the mortar left adhering to the mixing board and throw it on top of the concrete already in place. The other is to shovel the concrete up higher than the finished surface and then bring it down with a rake, the stones being pulled out and the mortar left on top. Of course neither of these tricks should be accepted as a substitute for the proper amount of tamping.

Concrete should be laid and rammed in layers, as far as practicable, normal to the direction of the pressure it carries.

Care should be taken in the ramming not to displace any braces, ties, forms, pipes, or other embedded fixtures.

Any portion of any layer of concrete which has been left long enough to have any appearance of setting should be taken up and relaid before the next layer is put on or may be treated as follows: When a fresh layer of concrete is to be put on one which has set or partially set, the entire surface must be thoroughly swept with metal brooms or brushes. The skin or film usually forming on the surface of the concrete must be completely scrubbed or steamed away.

All surfaces and pockets must be cleaned of all sawdust, shavings or other matter, and when completely cleaned, it should be thoroughly wetted before the new layer of concrete is placed.

Do not attempt to ram concrete under water; the cement will be washed off the sand and stone. (See Art. 36.)

Force of Rammers and Shovelers.—For distributing and ramming the concrete in place after delivery, a sufficient force of rammers and shovelers should be maintained for each mixer in operation to handle the concrete rapidly and ram or tamp it thoroughly before another batch is dumped within the forms, and when this labor is specially severe, the inspector should require the changing of men so employed in order that this part of the work may be thoroughly performed. In fact, effective ramming is hard work at which a workman should not be kept for more than an hour, when he should be changed to wheeling or mixing concrete. The men, if standing on the concrete, should wear india-rubber boots to protect their feet from corrosion by the cement.

A gang of twelve men will ram well and easily a cubic yard of concrete in six minutes in straight ordinary work. This gives an area of six square yards 6 in. thick.

Time Required for Ramming Concrete.—The length of time ramming or tamping should be continued and the vigor with which it should be done depend largely on the degree of plasticity of the concrete. Too much tamping is to be avoided, as it separates the mortar from the stone, bringing the former to the surface. The ramming should be stopped when the water flushes to the surface. In other words, a flushing of water to the surface should always serve as an indication when to cease tamping. The ramming or tamping in one spot or locality should occupy not less than three minutes and not more than five minutes as a general rule.

Tools for Ramming or Tamping Concrete.—Rammers are used for compacting the concrete. They may be made of an oak stick 18 in. long, 4x4 in. at the top and 3x3 in. at the bottom fixed to a handle at the top. Square wooden rammers measuring from 6 to 8 in. on a side, or round ones from 8 to 12 in. in diameter and weighing between 10 and 12 lbs., are quite often used. A rammer having a 2x4-in. face is convenient for use close to the forms.

Rammers are frequently made of wood, but those of iron are believed to be better. The rammer ordinarily used for dry or plastic concrete consists of a block of iron having a face 6 to 8 in. square and weighing anything up to 20 or even 30 lbs. A convenient rammer is made of an iron casting, 6 in. square, having a handle of 1-in. round iron, or 1½-in. pipe, about 5 ft. or 5½ ft. in length, which should weigh in all about 20 lbs. Twelve-pound metal rammers are also used, especially where only light tamping is required. For large work, pneumatic rammers built on the principle of pneumatic riveting machines have been used. The weight of a rammer is limited by the capacity for work of the man who wields it. Rammers have been made up to forty and even fifty pounds in weight. The rammer used need not be very heavy.

In all cases, tampers should be of such form and material as

the engineer may approve. The tamping tools should be at least 6 in. square at the bottom and should not exceed 18 in. square. Rammers of special shape or pneumatic machines may be required by the engineer to secure thorough work in different places. Special shaped tampers will be required for places where ordinary tampers would not be effective. Bevel rammers are necessary for the backs of arches; railroad tampers for heavy mass work; short-handled rammers in confined places and long-handled rammers in columns. In other words, there should be rammers of different sizes on the work, so as to be able to ram the concrete in all places. The surface of the rammer is sometimes corrugated, to keep the surface of the layer rough and thus give a better bond with the next, and also to transfer the compacting effect of the blow deeper.

Round and square iron tampers are the best for dry concrete work. Probably the square tamper is more serviceable for all kinds of work, because it will fit into corners.

Concrete to Be Free from Voids.—The concrete must be so thoroughly compact that there will be no pores or open spaces between the stones of which it consists that are not thoroughly filled with mortar and every effort should be made to secure the greatest possible density of the mass.

Tapping Forms to Produce Smooth Surfaces.—In addition to tamping or puddling, the forms of all concrete work—i. e., beams, girders, columns, etc.—should be lightly and continuously tapped with a suitable maul, in order to provide smooth and perfect surfaces. The outside of the forms should be pounded with wooden mauls or mallets immediately after receiving the concrete, to assist in shaking down and consolidating the concrete by breaking and forcing out air bubbles. This tapping must be done gently, however, to prevent the breaking of the formwork which at such times is under great pressure.

Removal of Defective Concrete.—Any concrete work indicating that it has not been thoroughly mixed in the required proportion should be dug out and replaced as directed by the engineer. The inspector, of course, will be governed by the engineer's decision in the matter.

Wetting Concrete.—When a deficiency of moisture is indicated after ramming is completed, it should be supplied by sprinkling with a fine spray of water. After ramming, a surface of concrete should be kept moist until it fully sets by sprinkling at short intervals. For this purpose not less than one large watering pot for each mixer should be kept in constant service, and as many more as may be required. (See Art. 29.)

No Walking on Fresh Layers of Concrete.—When in place, all wheeling, working or walking on the concrete must be prevented, until at least twelve hours after being deposited or until it has set for a sufficient length of time. Protection of concrete after placing is discussed in Art. 29.

Excess of Water in Concrete.—An excess of water is detrimental to the concrete, as it brings a layer of cement which has already

set to the surface, forming a point of weakness in the finished work, unless it is well scraped off before the next layer is deposited. If one or more batches are too wet, a comparatively dry batch or more should be mixed to take up the surplus water.

Introduction of Cells in Mass Concrete Work.—Where weight is not desirable, cells may be introduced in the mass, formed either by cheap hemlock boxes, which can be left in the work, or by collapsible boxes which can be withdrawn and used over again. Where weight is desirable, large stones may be rammed in the heart of the mass, as described in Art. 34.

Record of Concreting.—The concrete foreman should be required to mark in ink upon the plans the date and hour when each part of the work is concreted. This must be attended to every time concreting is done, and it must not be put off until some convenient time and then filled in from memory. The reason is obvious.

Sample Blocks of Concrete.—A sample block of concrete should be taken from the wheelbarrow during each day's work, to make sure that the concrete tested is exactly like what is used. This sample should be poured into a box, say 6x6x6 in. or 5x5x8 in., and the box should be dated, or better still, the blocks should have their date and their number scratched on their side surfaces, and their history fully recorded, and kept so as to obtain the same climatic conditions as the original. That is to say, each sample block must be exposed to the same weather conditions as the concreting which it represents. This will serve as a general guide to determine the condition of the concrete before centering is removed, although these blocks will not always harden at the same rate of speed as does the concrete in the structure. No practice is more dangerous than to take down forms and shores from under the concrete because of the hardness of the corresponding test blocks. (See page 248.) The author would suggest that signs be placed over the boxes containing the sample blocks of concrete, warning all workmen against moving these boxes or tampering with the contents; otherwise workmen are likely to pay little attention to this and constant watching on the part of the inspector is necessary to guard against their removal.

Cement Finish.—When the cement finish is less than 3 in. thick it must be deposited, practically simultaneously with the concrete as described on pages 298, 384 and 385. The finish must conform to the specifications and the drawings (see Chap. VII). The preparation of the concrete for a cement finish must be the same as that specified for the joining of new to old concrete work (see Art. 27). The face must be sprinkled with neat cement after it has been carefully cleaned of all foreign matter. (See also page 483.)

PLACING CONCRETE IN EXCAVATIONS AND FOUNDATIONS

Concrete should be placed in excavations by means of chutes or other appliances to prevent an excessive free fall (see Arts. 35 and 36). The contractor should be expressly prohibited from using

methods that will cause separation of the aggregate and matrix unless with special permission of the engineer in charge, and in such cases the concrete should be thoroughly remixed before being placed.

When used for foundations, concrete should, when practicable, be deposited and rammed against the sides of the excavation.

Foundations below Water Level.—Where concrete is to be put into a foundation below water level, all water should as far as possible be removed from the excavation. If it is impossible by means of the ordinary pumping facilities to control the flow of care must be taken to ram thoroughly the bottom layer of concrete may be placed in the foundation, section by section. Special care must be taken to ram thoroughly the bottom layer of concrete, and to remove all mud and clay from the vertical face of each section of concrete, as additional sections are excavated and prepared for additional concrete work.

Where the foundation is soft—as, for example, where piles are used—either fine or coarse broken stone may be spread over the bottom of the excavation and thoroughly rammed into the earth before putting in any concrete.

In no case should a dry mixture of sand, cement and broken stone or gravel be put into a foundation. The cement may be mixed with a less proportion of water, but must not be placed in the foundation without thorough mixing.

Where strata or gravel and sand permit the entrance of water into the foundation with such freedom that small sections of the same cannot be excavated and pumped out for concreting, a grout of pure cement or of a mixture of cement and one or two parts of sand may be injected through a pipe into the loose gravel and sand in the bottom of the foundation; this work being done while the excavation is filled with water. The pipe through which this grout is passed should be pushed a few inches below the surface of the gravel, and a bucketful or more of grout should be poured down through the pipe, the pipe being then moved 1 or 2 ft., and the operation repeated, distributing the grout over the whole area of the bottom to be thus cemented, and the work then should be allowed to stand for 24 to 36 hours. It will generally be found that the sand and gravel will be converted into a water-tight concrete, permitting the pumping of the excavation.

Foundation Concrete.—In foundations on poor soil, etc., where low grades of concrete are employed, it is important that they be thoroughly mixed and be deposited with particular care so as to assure uniformity and as great solidity as possible.

Foundation concrete may be put into excavations without the use of forms, provided the sides of the excavation are reasonably true and the material is sufficiently firm, so that the concrete may be rammed thoroughly without yielding of the adjacent earth. Foundation concrete, if put into excavations which are not protected by forms, need not have any special attention given to the finish of the concrete against the earth around it.

Where it is necessary to use forms in the construction of foundation work, the finer material of the concrete should be worked to the outer portion of the mass against the forms, so as to insure the filling with mortar of all pores or open spaces between the concrete stone. Where a cheaper kind of concrete is used for foundation work, the top of the same should be finished smooth and level, the corners and edges being thoroughly rammed and compacted, and the whole surface filled full of mortar. It will not be satisfactory to leave a honeycombed surface or one on which loose concrete stone is left scattered about. If necessary, the inspector should have the contractor make batches of mortar, consisting of one part of cement to three parts of sand, the same being thoroughly mixed, and should cover the whole surface of the foundation concrete with enough of this mortar to flush full all such open, porous places.

Pouring Concrete in Trenches.—When placing concrete in trenches containing water, as much of the water as possible should be bailed out, the concrete then being deposited from one end of the trench, driving what water is left to the other end. When water is gathered in this way, it may be taken up by placing some dry concrete.

Concrete should be lowered into trenches (over 6 ft. deep) in boxes or buckets, and not allowed to be cast in by shovels from the surface. The engineer may require, instead of buckets, that the concrete be dumped in inclined chutes (see Art. 35), the angle of the incline to be determined by him. The inspector, of course, will be governed by the engineer's decision in the matter.

Wetting Dry Trenches.—Before the first layer of concrete is put into the trench, the bottom of the trench must be thoroughly sprinkled with water from a hose, so that the water in the concrete may not be absorbed.

Footings.—Quite commonly, the hole or trench is excavated to the approximate size of the footing for cellar walls, columns, etc., and the concrete dumped in the hole without forms of any kind. Such practice is not to be recommended unless the ground is very stiff. On the contrary, as the stability of the entire building depends upon the integrity of the foundation, the greatest care should be taken both with the forms for the outside, with the banks of the excavation so that dirt will not fall into the footing, and with the proper placing of the steel. The latter should be protected with not less than 3 inches of concrete, preferably more, and the concrete around the rods should be rich in cement and dense, so as to exclude water.

In starting the footings, use a wet concrete, into each batch of which an additional bag of cement has been placed, for the first foot of height of the footings. Some constructors prefer to use dry concrete and to omit the additional bag of cement in the first batches for footings. In this case, the concrete should be mixed just wet enough to have the water flush to the surface when tamped. This

is not on account of considerations of strength, but because moderately dry concrete sets up quicker than wet concrete and is rather more convenient to handle.

Before placing concrete in cellar wall footings, it is a good idea to drive stakes in the trenches about 6 ft. apart, with their tops leveled to give the exact height for the top of the footings. The concrete can then be readily leveled with the tops of these stakes, which may be left in place without harm.

Footings should be cast at one operation where practicable, and the concrete deposited in layers not exceeding 10 in., and each layer thoroughly tamped or puddled. In other words, fill each footing, especially for columns, in a continuous operation until it is full; short intermissions of time not sufficient to permit the concrete to stiffen may be disregarded and considered as continuous filling.

The top surfaces of concrete footings, when finished, should be brought to a smooth, even surface, and should be finished with cement mortar, if necessary, to bring them to such a surface. If metal base plates are used under the columns, special care must be taken to prevent hollow places under the plates. This is best accomplished by setting the plates in a thin grout 1:2, examining afterwards each plate by pounding with a hammer or a brick.

Reinforced concrete footings cannot, as a general rule, be conveniently placed under water, so in a wet excavation it is advisable to use plain concrete footings of ample dimensions to meet all emergencies.

PLACING CONCRETE IN COLUMNS AND WALLS

Columns, walls and other deep masses should be given a chance to attain preliminary shrinkage before depositing adjacent shallow masses like floor slabs, beams, etc.

Size of Aggregate.—In columns, walls, etc, the aggregate should not contain particles of maximum diameters greater than one-third (1/3) the diameter between faces of adjacent reinforcing members, or between faces of forms and reinforcement. Otherwise voids may be expected through arching of pieces of the aggregate. Gravel is less liable to do this than broken stone.

Consistency of Mixture.—Concrete for columns and curtain walls should as a general thing be softer than concrete for slabs and beams. In other words, a comparatively liquid consistency of concrete should be used. It should be such that there is not quite enough water to wash cement from aggregate when dumped in large masses.

Pouring Columns.—The greatest caution and vigilance must be exercised in filling columns. To start with, it is not sufficient to inspect and clean out the foot of the column box just before pouring (see page 216), but look through it while open and lighted below, and assure yourself that no piece of wood or tile has fallen and wedged somewhere. Upon inspection, reinforced concrete columns are frequently found to be materially weakened because embedded

in them are shavings, chips of wood, blocks, and other building materials.

In monolithic construction, the columns should be poured a sufficient length of time ahead of the beams and girders to allow the concrete in the columns to settle and shrink, one day being preferable. This is important. Columns have been observed which have shrunk one-half inch in twelve feet. The inspector should insist upon columns being filled at least six (6) hours ahead of beams and girders; the interval may conveniently be utilized in putting the floor-steel in place (see page 274).

Before the regular column mixture is poured, there should be at least 2 or 3 in. of mortar in proportions 1 to 1, placed in the bottom of column forms. Some specifications require that the lower 1 ft. of each column shall be filled with a concrete containing more sand and less stone than the regular mix, under the instructions of the engineer, in order to avoid any "honeycombing" at this point, the balance of the column being filled with concrete mixed in the proportions specified. The following clause was used in Government specifications for a postoffice at Fort Collins, Colo.: "Immediately before pouring, the concrete column and pier forms shall be filled to a height of 2 ft. with 1 to 2 mortar of same consistency as the concrete." Other specifications require that before beginning to fill the forms of columns, the bottom or bearing surface must each time be thoroughly slushed with a neat cement grout. The inspector, of course, will be governed by the engineer's instructions in the matter. The author would suggest that in every case a small batch of mortar be used for the bottoms of columns and at the start of a day's work, and a final batch largely of aggregate be used for tops of columns. Otherwise, the bottom of a column is likely to be all stone, and the top all grout or possibly nothing but water.

In pouring a column it is best always to fill the column from the center. The author has seen cases where the concrete was poured in from the side of the column and the spaces between the hooping and the form filled up more rapidly than the center of the column, the mortar was strained from the coarse aggregate, flowing to the center of the column and leaving the outside face of the column full of voids and the fireproofing portion outside of the hooping being of no strength whatever, making it necessary to remove it and cast the outer shell of the column.

In filling columns the concrete should be poured in small batches, preferably by dumping the wheelbarrows on the floor, and shoveling the concrete into the column. The operation should preferably be continuous from the base to the underside of supported beam or girder, but if stopped short of completion, the unfinished surface must be left level. It is the practice with some contractors not to pour the entire column at one operation, but to allow a height of about 4 ft. to set for three or four hours before the second pouring. When laying concrete in columns, a continuous spading should be kept up during the operation so that it will make a smooth surface

when the column forms are removed. It is absolutely necessary to expel bubbles of air by constantly puddling or joggling the concrete with a rod heavy enough to sink into the concrete with ease. The outside of column forms should also be hammered with mallets, during the process of pouring, so as to exclude air bubbles and make a smooth surface.

When placing concrete in column forms, care must be taken that there are no washers or other obstructions in the way of the falling concrete, which would interfere with packing the concrete. Washers are sometimes used on the vertical bars to keep them away from the forms, but these washers prevent the concrete from falling and often on the removal of the forms there is found a cavity under the washer which the concrete did not fill.

Column forms should invariably be filled before the reinforcement for beams and slabs is in place; otherwise it will be very difficult to fill them.

An experience of the author in pouring columns may be of interest. The gravel contained about 5 per cent of clay. The columns were poured with very wet concrete which churned up and down. This brought the fine clay to the surface and resulted in a stratum of worthless material perhaps 2 in. thick. Fortunately, this was discovered before the top of the column was poured. It seems advisable to wash material of this kind under these conditions. (See page 103.)

The columns of a reinforced concrete building in a town in Texas had honey-combed appearance in many places on the surface, the holes sometimes extending in an inch or more. The reason for this was that the forms were not tight enough and the mixture was put in unusually wet. The water in leaking through the forms carried out some of the cement and sand with it. As a matter of fact there was no danger to be apprehended in this case, although the appearance was somewhat unsightly. In a few of the columns there were some fairly good sized holes on the surface. The author believes this to have been due to the fact that too large a size of stone was used in the aggregate and this, together with the fact that there was rather an excess of reinforcing material, made it impossible to do much puddling or tamping, so that some of the larger stones wedged against the sides of the forms, leaving holes underneath.

Tamping or Puddling Columns.—At least one man should continuously tamp or puddle a column, during the process of concreting, by means of a stick of lumber 1x2 in. (or 2x2 in.), or with thin tampers that will go in and around the reinforcing steel at all four sides simultaneously. Care must be taken that the column bars keep their place while concreting the columns, and for this purpose the tops of the bars should be steadied by wires or boards. Special care is needed in puddling the concrete in columns to make it flow around the reinforcing rods. Puddling should be thorough, as its purpose is to work the concrete closely around the reinforcement and into the angles of the mold and to work out air bubbles. During the operation, the concrete in the column must be constantly churned in order to prevent arching in the interior of the

column, by being freed from air bubbles. Ramming on top will not accomplish this result. Long, slender poles with flat steel ends may be used advantageously for puddling the concrete in columns. At least two of these rammers should be constantly used in large columns during the pouring of the concrete. A tool resembling a broad chisel is one of the best devices for puddling or slicing.

Columns Over 12 Feet in Height.—Columns more than 12 ft. high should be poured from a point half way up and at the top, so that the concrete will not have so far to drop and so that puddling of the concrete around the reinforcement can better be effected. Openings left in the sides of column forms, to facilitate pouring should, of course, be closed when the concrete reaches that point, and the remainder of the column then poured. Constant puddling is equally necessary in long columns.

Concrete in long columns may also be deposited continuously through tremies, in order that the stone and the mortar may not be separated. Ordinary columns may be filled in a similar manner. A method often adopted for filling columns is to have a pipe made in sections with a flaring top. This pipe goes nearly to the bottom of the column and the concrete is poured into it. The pipe is raised from time to time and churned up and down. When it rises so that a section can be removed, this is done. (See also Art. 36.)

Minimum Time for Filling Long Columns.—Where columns are of an unsupported length of more than twelve times the least diameter, the filling should be done gradually, and to every foot of height there should not be less than ten minutes' time used to insure minimum amount of contraction, due to the setting of the mixture.

Spiral Columns.—In columns having spiral or circumferential reinforcement the concrete should preferably be introduced by means of a tremie or tube, in order to prevent the ingredients from sorting in layers. (See Art. 36.)

Pouring Flat Slab Columns.—In pouring, the column and cap or head should be filled first completely, then proceed to pour the concrete in the slab.

Excess of Water in Columns and Walls.—Particular care must be given to the filling of columns and walls not to have an excess of water, the whole must be uniform from bottom to top. If water accumulates on the concrete, churning or working should cease until additional dryer concrete is placed to prevent the washing out of cement. (See pages 195 and 302.)

Pouring Walls.—Walls should be blocked off into convenient lengths and the whole work brought up uniformly along this section to prevent long, wedge-shaped layers of concrete. Upon stopping, the concrete should be brought up to a uniform level. A panel should be of a size that can be completed in a day's work. (See Art. 26.)

It is well to keep in mind that the thinner the wall the stronger and denser should be the concrete.

For curtain walls the concrete is generally run fairly wet and in

place of tamping is usually stirred with rods. In other words, soupy concrete should be used for curtain walls, but not so wet that the mortar is watery. Don't dump large quantities of concrete into narrow forms. The concrete should be puddled rather than rammed, the object being to prevent stones from collecting in any one place, and causing noticeable voids on the surface. Puddling is quite as effective as ramming, if properly done. (See page 296.)

In filling curtain walls, if the wall is solid throughout its length and height, it may not be possible to fill an entire story at one operation, in which case it makes little difference whether the wall is filled up half way all around. or a section filled up the entire height of the story. As the concrete is usually dumped into the wall forms from the top, a long pole similar to that used for columns mentioned above is necessary to churn the concrete as it is deposited, and a long-handle spade should be used to spade the concrete next to the form to push the large stones away from the forms and thus avoid a honey-combed appearance when the forms are removed. Care should be taken not to make the concrete too sloppy in filling high walls, as the stones are apt to settle to the bottom, forcing the cement and sand to the top, thus making laminations in the wall. This would be visible after the concrete is dressed, should the wall be left to set hard before it had been poured the full height. Great care is necessary to overcome this defect. Further, the top of the concrete should be scraped off before applying the next run, as a thick film of inert material usually rises to the top of the concrete which if left will weaken the wall at this point.

No rods used to hold the forms apart should be allowed to pass through the wall, except with permission of the engineer.

Forms are designed for a certain number of vertical feet rise for a day's concrete work. Find out how many vertical feet. If for any reason the concrete is changed from a dry concrete to a wet one, consider the number of feet rise permissible under the changed conditions.

Concrete should be laid in layers not exceeding 6 in. in depth when deposited dry; if thicker than this, it is apt to lose a part of the benefit of the labor of tamping—the effect of the blows not penetrating to the bottom of the layer. Wet concrete may be deposited in layers of 10 to 12 in., thoroughly puddled. (See page 296.)

Concreting Hollow Walls.—Sometimes it is necessary to form an air space in concrete walls; this may be done by using a number of loose planks the thickness of the air space, about eight or ten inches wide, and tapering them a little, oiling them and setting them vertically midway between the two sides of the form. If the space is to be in the middle, these planks should be located about three inches apart, and should be long enough to project above the concrete as it is poured. When the concrete has started to set, the planks should be pulled up, leaving the lower end project into the concrete just placed; in this way the planks are removed, leaving an air space, and can be used over and over again to make similar hollow spaces in the

wall. The three-inch space between the planks leaves the concrete flow from one face of the wall to the other and thus makes a tie.

Concreting Spandrel Walls.—Spandrel walls cannot be carried up at the time that the lintel and slab forms of a building are filled, especially if wet concrete is used. Therefore, the concrete must first be deposited to the level of the top of the slab (see page 312), and when this has its initial set, the balance of the wall may be filled. If this precaution is not taken, the hydrostatic pressure of the wet concrete in the spandrel wall will force the concrete from underneath the form at the slab and prevent the filling of the wall form. (See page 318.)

Concreting Retaining Walls.—Where walls occur below grade and act as retaining walls, the sheet piling, if any is used, is generally used as the outside form and allowed to remain after the concrete is poured. A wall of this sort cannot be poured the entire height at one time, as there are horizontal stringer pieces braced to the ground to hold the sheet piling against the bank; in such cases the forms are filled to a little below the bottom of the stringer, and after the concrete has hardened, another stringer is placed on the outside of the forms of the retaining wall where it has been filled and new braces introduced, being wedged up to take the thrust on the wall, when the original stringer and braces can be removed and the rest of the wall cast. This method of filling retaining walls removes any danger of the thrust of the bank shifting the forms.

PLACING CONCRETE IN SLABS AND BEAMS

When placing concrete in slabs, beams and girders, commence at the farthest point from the elevator or hoist and work toward the hoist. In this way it will not be necessary to wheel loaded barrows or to have the workmen walk over the freshly deposited concrete before it is set hard.

General Requirements.—In placing concrete in the floor slabs, girders and beams, the work should be, if possible, carried along in a straight line on the section of the building which is being concreted.

When placing concrete do not dump directly into place but back a little on that already in place, then by puddling and shoving cause the newly dumped concrete to run or flow down into the beams or floor slabs.

Where smooth surfaces are desired in slabs, beams and girders, it is preferable to spread a thin layer of rich mortar, say about ½ in. thick, over a section of the area to be concreted ahead of the regular mixture. Much better and smoother work will result.

Unless adjoining masses of concrete of different depths like adjacent girders and slabs have the puddling or ramming operation carried down as thoroughly through one as the other, initial setting cracks are likely to form between the masses of different depths.

Pouring Slabs.—In making slabs, the full thickness must be

poured in one continuous operation. Work must never be stopped off at horizontal planes. Stakes should be placed from place to place showing the thickness of the floor in order to insure a level floor. If possible, slab and beam must be made monolithic. The units of construction as indicated on the drawings should be rigidly observed, and each unit completed at one time. The floor slabs may be made in sections, provided that the ends of all sections coincide with the center of beams. (See Art. 26, page 324.)

Expanded metal and woven-wire floor slab reinforcing is usually stretched across the forms before any concrete is deposited, then a thin layer about an inch thick of concrete is spread uniformly over the metal and with a hook or the corner of the shovel the metal is pulled up through the concrete, leaving this thin layer on the forms with the metal reinforcement lying on top. Then the rest of the concrete is deposited and rammed in place. This places the metal reinforcement about three-quarters of an inch from the bottom of the concrete slab. Unless care is taken to bring the metal up through this thin layer of concrete the metal will show on the underside of the slab, and this is sufficient cause for rejection under the building laws of the larger cities.

During the pouring of floors there should be at least two workmen assigned to giving their undivided attention to this work. Care must be taken to raise slab reinforcement the proper distance above centering as concreting progresses; or, better still, use some automatic spacers for the accurate placing of the reinforcement (see page 274). The tamping of the forms with iron rods or bars so as to raise the steel reinforcement from the centering should not be permitted. The slab rods, if not arranged with a spacing or registering device, should be pulled up into the concrete work, or if placed in conjunction with the concrete, they should be laid upon a thin layer of concrete as mentioned above. The method of pouring a slab and allowing the material to slope down over the beams and girders and then beginning the next day gives a slip slab joint which should not be allowed.

In slab work, the concrete is best compacted by tamping or rolling. A broad-faced rammer should be used for tamping wet concrete (see page 301), or a wooden roller covered with sheet steel, weighing at least 300 lbs., and having a 30-in. face. The compacting of floor slabs is sometimes done by rolling: first, by using a 3x3-ft., 350-lb. wooden roller, then a $2\frac{1}{2}$x$2\frac{1}{2}$-ft., 500-lb. iron roller, and finally a $2\frac{1}{2}$x$2\frac{1}{2}$-ft., 700-lb. iron roller. The rolling should be continued until the effect thereof is not apparent.

If a granolithic finish is to be put on the floor, have this immediately follow the placing of the under concrete, even when shores are to be placed upon it at once. (See Art. 51, page 480.) If done subsequently, the cement finish will not adhere to the concrete, and may crack and come loose.

After the floor slabs have begun to set they should not be walked on or wheeled over until hard, as otherwise their strength

is seriously injured. If traffic over them is unavoidable, boards should be provided for the purpose of distributing the weights. (See Art. 29.)

Any preliminary shrinkage cracks which occur on the surface of the slab due to too rapid drying should be immediately filled with liquid cement grout.

When putting concrete filling on top of floor slabs or around floor sleepers, see that all dust and dirt is brushed off the concrete in place and that it is drenched thoroughly before depositing the filling. (See Art. 37.)

The concrete should be completed in any one unit part before the initial set appears on its surface.

Reinforced Concrete Joist and Tile Construction.—Where hollow tile is used with the floor system, it should be of the best quality, vitrified clay, with walls and webs not less than 3/4 in. thick. Dense or semi-porous tiles may be used, it makes little difference in the results which is selected. The surface should be deeply scored so that the plaster may be firmly bound to the tile; only in the roughest kind of work are the tiles left uncovered on the exposed bottom side. The bottom of the tile should in no case be broken, but a slight break in the upper part is not objectionable, provided that the concrete is allowed to flow into the same. Broken, badly warped, or otherwise defective tiles, should not be allowed.

The tile must be placed regularly at equal distances apart, and absolutely straight and true for the reception of sleepers, etc., and at such distances apart as shown on drawings. The tile is generally spaced 4 or 5 in. apart. A wooden strip of the proper width should be laid between the lines of tile when a new line is being laid, to serve as a spacer, and also to get the proper alignment. When the line of tile has been spaced, the spacer can be removed and used on the adjacent line. Under no condition must the joist between two rows of tile be made crooked or with non-parallel sides. It is advisable, in placing the tiles, that the long lengths be placed in the center of the span and the joints be made to alternate in the adjoining rows. The tile should be laid with as close fitting end joints as possible.

After the reinforcement is put in position the concrete is poured, care being used to avoid pushing the tiles out of place. Sometimes at least a full inch of concrete is filled in over the entire bottom before the steel is placed in position. The concrete on top of the tile must be poured at the same time as the concrete in the joists. Unless this is done the floor will be greatly weakened, and might have to be removed at great expense. Even where concrete is not specified to go on top of the tile, allow enough concrete in the joist to flow over the whole top surface of the tile for a thickness of about 1/4 in. Especial care must be taken to form T-shaped beams by stopping the rows of tile back from the edge of the beams as shown on drawings, and covering the ends of tile with tin to prevent the concrete from flowing into same.

The tile must be thoroughly wet before placing the concrete, especially in warm weather, as they will otherwise absorb the moisture from the concrete.

Pouring Beams and Girders.—Beams are sometimes poured in one continuous operation from bottom to top. This method of pouring beams or girders up to the bottom of the slab and then afterwards placing the slab is not desirable. In all instances, the slab should be formed in conjunction with the beams and girders. The filling of the beams and girders flush with the top of the slab centering and allowing it to remain should not be permitted. In slab and beam or girder construction, the pouring should invariably be continuous from bottom of beam or girder to top of slab. Work should never be stopped off at horizontal planes.

Pour beams and girders from one end, dumping the concrete on concrete, letting it run down around the steel reinforcement and into all sharp corners. This will avoid archings of the concrete over reinforcement and will give a smooth job when forms are removed.

To get a smooth finish on the surfaces of beams and girders, the concrete against the sides of the forms should be carefully "spaded" in order to prevent voids and to push large stones back from the forms, and allow fine material to show at the surface. As in columns, careful puddling is essential in pouring beams and girders. In fact, churning and spading the sides of beams and girders is absolutely necessary to obtain neat-appearing surfaces. The sides of the forms should be pounded with a heavy hammer, so as to settle the concrete and help to break and force out air bubbles. At least one man, but generally two men, will be required to tamp each beam, during the process of concreting, by means of special spades. Care must be taken that the stirrups remain in their places and are held up tight against the underside of beam or girder tension bars while concrete is being placed, and that neither is disturbed or shifted by the process of ramming or puddling. The concrete should be flat-spaded along the sides of all beams and girders. (See page 297.)

Beams and girders are sometimes filled in two operations, the concrete being first carried up to the tops of the bottom bars, and immediately after being thoroughly tamped or churned by striking the bars with the tamping tools, the beams and girders are completely filled and carried over the slab in one operation.

When beam and slab are designed to act together as a T-beam, both should invariably be poured in one operation. No portion of the work must be started unless it can be pushed to completion, except by special permission of the engineer. Do not fill the beam or girder early enough to permit the concrete to take its initial set before the slab is concreted.

No stops should be allowed on extra long beam or girder spans and special arrangements should be made to do the entire work in one operation. Where the concreting of large beams and girders proceeds from one end, and the working face of the concrete body is sloping, the excess of water naturally seeks the lower level in the part of the beam or girder box not yet concreted. The water carries

"laitance" with it, and this sets without hardening, forming a white, plaster-like film on the bottom of the beam or girder, often ½ in. thick or more. Such conditions should, of course, be avoided.

When pouring a beam the operation should not be left unfinished for any length of time.

Concrete should be so poured as to reduce flowing and spreading to a minimum. As long as the mass is kept moving it will be homogeneous; but if it is allowed to set in this shape two evil results will follow: *First,* the cement and water, the most fluid part of the mass, will flow forward, leaving behind a layer consisting chiefly of sand, with which the concrete, subsequently placed, will not mix, and which has very little value as fireproofing; *second,* the scum which rises to the surface of wet concrete containing as it does the finest dust present in the sand and stone, sets with a very smooth, glassy surface to which fresh concrete will not adhere. This joint, therefore, if work is stopped on it long enough to allow the scum to harden, will be very weak in shear and tension. (See page 293.)

Concrete Fireproofing of Steel Beams.—When putting concrete fireproofing around steel beams, the soffit of the beams should be covered with a mortar mixture of cement and sand, thin enough so it will run under the beam and fill the space where it would be difficult to force concrete made with a large aggregate. The mortar should be forced through from one side until it appears on the opposite side of the beam. This will insure the space being filled with mortar. If the mortar or concrete is put in on both sides simultaneously and rammed, the air under the beam will be confined and will cause a pocket or void in the concrete soffit of the beam. Care must be taken to see that the concrete is forced under the beam, so the space beneath will be filled solid.

Shoring Floor Forms.—During the process of concreting, the inspector should see that a careful workman is stationed underneath slabs, beams, girders, etc., to watch for any deflection in the forms and do any necessary wedging up. A workman should be employed at all times watching centering while concreting is being done—this watchman to stretch wires from column to column to guard against deflection, and to see to immediate strengthening of centering where necessary.

Precautions to Be Observed in Concreting around Reinforcement.—Take great care that concrete is carefully deposited in columns at floor levels where reinforcement from columns, beams and girders meet. See that no voids are left under rods and that good quality of material gets into the work. Better use a special batch of specially rich mixture at each such point. Whenever there is a nest of cross-bars that the concrete will not readily penetrate, pour into same sufficient cement grout 1:2 to thoroughly fill all spaces. Special care must be taken, especially in hot weather (see Art. 32), to follow up this grout with the body of the concrete before the grout has stiffened. If the circumstances are such that the grout stiffens too quickly for convenient working, time may be gained by throwing on the face of the grout sufficient fresh

concrete to cover it, and in turn should this fresh concrete stiffen before it is covered with the main body of concrete, it may be renewed from time to time as above by further small additions of concrete. It is, however, important that neither the original surface nor any of the renewed surfaces be allowed to stiffen before the next layer is applied. (See Art. 27.)

PLACING CONCRETE IN ARCHES

No work should be started on arch rings until piers and abutments have been examined and permission given by the engineer.

Quality of Concrete.—The concrete of the arch ring should be of the best quality, especially if steel reinforcement is not used. For this purpose, the stone, broken to a size not exceeding two inches in any dimension, should be mixed with a quantity of mortar a little more than sufficient to fill the voids, and composed of one part Portland cement to two parts sand. Interiors of piers and abutments may be made of a poorer mixture, such as one part of Portland cement to three parts of sand and six parts of broken stone or gravel, or even in some cases where abutments are massive, one to four to eight concrete may be employed.

Division of Arch Ring into Sections.—Wherever possible, it is best to make the concreting of the arch continuous, so that there will be no possibility of a future separation on a plane bounding two days' work (see Art. 26). Where it is impracticable to concrete in one continuous operation, the arch ring may be divided into sections, either *longitudinal* or *transverse,* each section representing a day's work. Both methods have given equally satisfactory results. A method that has been largely employed is to divide the arch into longitudinal rings by planes at right angles to the arch axis.

The author is of the opinion that the better practice, however, is to build the arch as a series of voussoir courses beginning with the springing course, but not necessarily proceeding in order from the springing to the crown. In fact, the order of the work may be so arranged as to distribute the loading on the centers in any manner desired. The advantages of this method of building the arch, in transverse courses parallel to the axis of the intrados, are that the planes of weakness may be made at right angles to the line of pressure; the unequal loading, and consequent settlement of the centers, has less tendency to crack the sections or to separate one section from another. In other words, any settlement of the centering will not weaken or fracture the concrete before it has set, especially if the last sections concreted are at or near the springing lines. When the arch is concreted in longitudinal sections there is danger of the sections separating along the plane between adjacent sections. Again, undue strains may be brought upon the concrete from a variety of causes before it has set sufficiently to attain its full strength. In cases of failure of concrete arches under excessive floods, the tendency of the arch to separate along a longitudinal joint forming a plane of weakness has been clearly shown.

Concreting Arch Ring in Sections.—In concreting arches, the

arch ring should be divided into sections of such size that the pouring of each can be made a continuous operation. Transverse and longitudinal arch blocks should be cast continuously and the contractor should not be allowed to start such work unless provided with sufficient plant and material to insure the finish of such a section continuously.

In longitudinal sections, the concrete should be begun simultaneously at both skewbacks and continued uniformly and continuously to the crown. That is to say, the construction of the arch ring must proceed continuously and without interruption from the time it is started until completed, work being begun at both abutments simultaneously, and carried at a uniform rate of progress therefrom until joined in completion at the crown of the arch.

Where the sections are transverse or across the arch, the better practice is to concrete the crown section first and work towards both skewbacks a pair of sections, one each side, at a time.

Concreting in Longitudinal Sections.—Should the size of the arch be such as to make it impracticable to construct the entire ring in one day it may be divided vertically into a series of parallel rings of such width that one ring can be constructed continuously. These strips or rings are practically arches in themselves. The width of such rings should, however, in no case be less than 5 ft., and should be so chosen that none of the reinforcing steel is exposed at any joint between two days' work. It is well, if this method of placing the concrete is used, to so divide the arch that a complete ring may be placed without intermission. That is to say, sections of the arch along the axis are to be limited to such length as to permit of the concrete being deposited continuously between springing lines.

One side of the sub-ring should be formed against the ring previously constructed, and the other side against a substantial vertical partition which must be removed immediately before commencing the next ring. This could be removed in a day or two, when the concrete would still be green enough for the next ring to adhere pretty well. In order to form a substantial bond between the adjacent parallel rings, cleats should be fastened to the partitions in such locations and of such shape and dimensions as may be directed by the engineer. (See Art. 27.) In constructing new rings against old ones, the vertical surface of the old ring should first be thoroughly cleaned and scrubbed with coarse brushes and water and then flushed with cement grout immediately before placing of the new concrete. The arch rings may also be connected by steel clamps or rib connections built into the concrete.

While concreting is in progress the action of the centers should be carefully observed. Generally, as the load on the haunch increases, the crown will tend to rise. If this tendency becomes excessive, it may be overcome by loading the crown with any material that is convenient, or by placing the concrete for the crown of the arch before proceeding farther with the haunches.

Concreting in Transverse Sections.—When the sections are trans-

verse, the concreting may commence either at the crown or the springing, care being taken that no joint is made at the crown, and also that the concreting proceeds symmetrically on both sides of the crown. The division of the work into voussoir courses should admit of such size molds or blocks that two, one on either side of the center, may be completed in a day. The blocks are usually first placed near the springing line, then, to overcome the tendency of the crown to rise, the block or strip at the crown is placed and so on until the arch is completed. If it becomes necessary to interrupt the laying of a block, however, a vertical bulkhead should be constructed in the mold, with key or dowel pins if desired, to assist in making a bond when the block is completed (see Art. 27).

While the arch is being concreted, the centering should be carefully watched, and if it shows any tendency to rise at the crown, it should be loaded with concrete materials until such tendency is overcome.

Placing Layers of Concrete.—The thickness of the layers and the degree of ramming should be such as specified for other concrete work mentioned at the beginning of this article, but the layers should be placed as near radially as practicable, and the ramming done in a direction as nearly at right angles thereto as possible. This is difficult to do without setting up temporary forms normal to the arch ring and tamping beside these. This is an argument for the use of wet concrete in arches, as it is not important to have the layers of wet concrete normal to the line of thrust except at quitting time. (See page 296.)

In the abutments of arches the layers should be sloped as nearly as possible normal to the direction of the line of thrust of the arch.

Great care must be taken at the joining of the new concrete, in order that it may be as nearly monolithic as possible. The joint should be made rough, to assist in securing a firmer bond. (See Art. 27, page 326.)

Placing Concrete around Reinforcement.—Great care must be taken that the concrete entirely surrounds the reinforcement and that the reinforcing material is not displaced in the slightest degree in concreting. The spacing and location of reinforcing material are designed very accurately to meet the stresses in the arch, and unless great care is taken in placing the reinforcement (see page 281) and in concreting, the reinforcement will not fulfill the mission for which it is designed. (See pages 269 and 315.)

Spandrel or Face Walls.—The spandrel or face walls may be carried up at the same time as the arch ring, or may be connected with it later by leaving short lengths of steel projecting radially from the concrete of the arch. Some specifications require that arch centering shall be lowered sufficiently to allow the arch ring to assume its permanent set before parapet walls are placed. Where practicable, it would be well to leave the concreting of the spandrel wall of an arch span until the arch ring has hardened and the forms are removed. The settling of the arch often cracks the spandrel wall and gives an unsightly appearance to the bridge.

Finish.—To provide a smooth face, a thin facing mortar of one part Portland cement to two parts sand is desirable, laid at the time of building the concrete in accordance with methods described in Art. 41, page 385. A thicker layer of granolithic may be used on the soffit and will somewhat more effectually prevent the broken stone or gravel of the concrete settling on the lagging, which is always likely to occur, to the detriment of the appearance of the finished work.

The division between adjacent voussoirs should be clearly marked on the face, and additional joints may be indicated if desired, by lines in a plane approximately perpendicular to the line of pressure. Such lines are obtained by securing triangular strips on the inner face of the forms. When spandrel walls are used, these may be similarly marked on the face by horizontal and vertical joints.

Where concrete is placed on top of sheathing, as in the roofs of tunnels, culverts, sewers, etc., a layer of granolithic should first be placed as mentioned above, in order to insure a smooth finish to the interior, and the concrete above should then be thoroughly tamped into it.

For methods of finishing concrete surfaces, see Chapter VII, page 384.

Expansion Joints.—Expansion joints are usually provided for the spandrel walls or arches at each pier and at the abutments, to allow for some movement due to temperature changes. On long spans the spandrels should have expansion joints, and the coping and parapet, when of concrete, should also have vertical joints to provide for changes in length due to loading or thermal variations. (See Art. 28.) See that expansion joints are constructed exactly according to the engineer's plans.

Expansion joints may be made by placing in the joint several thicknesses of corrugated asbestos board, protected by $\frac{1}{8}$-in. lead plate folded into the joint to form a trough at the top. An asphaltic coating may then be placed over the lead, covering the whole; this gives an elastic and perfectly waterproof joint. Tongue-and-grooved joints are sometimes used, but it is believed that a lead covering as described above will prove the most satisfactory. Expansions joints in the spandrel walls may also be formed by laying the concrete against a vertical form and then butting the concrete of the following section against this smooth surface with a sheet of tar paper inserted between.

Waterproofing.—It is customary to waterproof the top of the arch ring and arches over the spandrels either with a Portland cement grout (see page 439) or a coating of asphalt (see page 446). The instructions for waterproofing mentioned in Chapter VIII may generally be applied to concrete bridges.

Drainage.—Pipe drains should be provided to carry the water to a point over the piers where it may be discharged. Care should be taken that such pipes have their outlets so located that the drip shall not disfigure the wall. Open spandrels may be drained by pipes built into the arch ring at suitable places. Bronze should be used

for the drain pipes, as iron or steel pipes will rust and discolor the masonry. Pipes, gutters, etc., intended for drainage must be kept clear and unobstructed by plugging or protecting such channels from accidental choking or filling with concrete or other material until they are finally covered or capped.

Backfilling.—Backfilling is usually begun after the arch has hardened but before the centers are struck. The reason for this is obvious. If the filling were placed after the removal of the centers, it would be necessary to place the filling uniformly over the arch, as filling a large weight on one side while the other is unloaded might so seriously deform an arch as to endanger its safety.

On the other hand, when parapet walls and railing are built before the centers are removed, the settlement of the arch may cause these to crack badly, and while this would in no way endanger the safety of the arch, still it is unsightly and therefore to be avoided. It would therefore appear that in some cases, particularly where, instead of earth backfill, a system of relieving arches, etc., is used, that when possible the centers should be removed and the arch allowed to settle in place before that portion of the work above the arches is begun.

The fill over arches should not be put in too soon after concreting. Generally speaking, at least two weeks should elapse before any fill is placed over the arch, but conditions sometimes necessitate shortening this time. In such cases, the inspector should get definite instructions from the engineer. (See page 461.)

Concreting Groined Arches.—Vaulted roofs should be laid in alternate squares, the lines of division being through the crown of the groined arches. In laying the concrete, joints between the work done on consecutive days should cut the arches at right angles to their axes, and bulkheads should be used to make such a joint a vertical plane. The covering of each unit between four piers should be made monolithic. Care must be taken to prevent the stones working to the bottom of the mass and thus becoming exposed when the forms are removed. This may be prevented by plastering the forms with mortar as mentioned above and placing the concrete upon it before the mortar has begun to set.

Art. 26. Joints Due to Stopping of Work

Theoretically, concreting should be a continuous operation, but practically it cannot be made so. All concrete work must be constructed along proper structural lines and when a section or panel of reinforced concrete or any trussed concrete member is started, it should be finished in its entirety before shutting down, but when this is not possible, the resulting joint should be formed where it will least impair the strength and appearance of the structure. Bonding fresh concrete to concrete that has hardened, though it has been done with great perfection by certain methods as described in Art. 27, must still be held as uncertain. Ordinarily, at least, a plane of weakness exists where the junction is made and in stopping off

work it should be done where these planes of weakness will cause the least harm. To effect this, the finishing surface should be normal to the line of thrust and it should not be where there is any considerable shear.

The author has observed in bridge piers and retaining walls that where one day's work joined that of another, lines could be noticed, and in many cases these lines were inclined, sloping at about the angle of repose of the wet concrete. By inserting partitions in the forms, these lines would have been vertical.

GENERAL REQUIREMENTS

Care must be taken in the location of and in the manner of constructing the connecting joints as the work progresses. Joints must be made only at such points as may be approved by the engineer. If the appearance of the finished face is of importance, special care must also be exercised in joining at this joint.

Joints between Day's Work.—Joints in the concrete work should not be allowed except at the natural end of each day's run; it is therefore essential that the plant be in such shape that breakdowns are avoided. Joints between day's work should be at some feature line, or be made truly straight and level. Work may be roughened to good advantage, but should never be left with a slanting surface or with loose material covering it.

Care should be exercised in the formation of joints in concrete work, especially in conspicuous places. A poor or unslightly joint not only mars the appearance but may affect the strength of the member or structure as a whole. The first and last batches of concrete, therefore, deposited in each day's work should be especially well damped and all surfaces brought to a level and roughened up afterwards where more concrete is to be placed upon it, but never left rough due to insufficient tamping. (See page 381.)

The methods employed to stop a day's work and leave the joint so as to make a satisfactory union with the engineer's directions must be carefully followed as to the location of and methods of constructing joints between day's work. Work can be stopped for the night along almost any line, if proper care is taken in joining work, and if work is continued after an interval not exceeding 48 hours, while the concrete is still comparatively fresh. (See Art. 27.)

A wooden strip nailed horizontally to the interior of the form-work, forming when later removed, a groove or false joint, an inch or so deep in the exposed face of the concrete, may be used to advantage to mark the end of one day's concreting and the beginning of the next, and the concrete stopped off at this level. This groove not only adds to the appearance of the structure on exterior surfaces, hiding what otherwise might be an unsightly joint, but is an effective means of breaking the monotony in the face of long stretches of concrete.

If walls or floors are to resist water pressure, take especial care at the joining of different days' work. Shrinkage cracks are more

likely to occur along such joints than at any other points. The best method of making them as water-tight as the remainder of the work is to use asphalt or coal tar with a strip of waterproofer's felt. (See Art. 50.) In walls, both horizontal and vertical joints must be equally cared for.

Be exceedingly careful about joints between portions of work done at different times. Unless the masses on the two sides of the joint are absolutely alike in quality, the joint will be visible and no amount of surface treatment except by plastering (see page 410) can entirely eradicate the blemish.

Precautions Regarding Horizontal and Vertical Joints.—Layers of concrete should be kept truly horizontal, and if, for any reason, it is necessary to stop work for an indefinite period, it should be the duty of the inspector and of the contractor to see that the top surface of the concrete is properly finished, so that nothing but a horizontal line will show on the face of the concrete, as the joint between portions of the work constructed before and after such period of delay.

It cannot be too strongly insisted that the line limiting the height of the concrete at the face should be made perfectly horizontal, for a slight crack, or at least a noticeable line, may be expected at this point, and if not straight it will be the more unsightly. If for any reason it is impossible to complete an entire layer, the end of the layer should be made square and true by the use of a temporary plank partition. In the construction of arches, culverts and sewers, such stop plank should be set normal to the surface of the intrados, instead of vertical. In case more than one layer is left incomplete, they should be stepped back, making an offset for each layer of at least one or two feet. No irregular wavy or sloping lines should be permitted to show on the face of the work at different periods, and none but horizontal or vertical lines should be permitted in such cases. The top layers of concrete should be left roughened up or grooved out along their center line in order to form a positive and water-tight bond with subsequent work. (See page 326.)

Every time a day's work is finished and a horizontal joint is thereby required, the concrete should either stop 6 in. below a wale, wiring or rodding, or 6 in. above. If stopped 6 in. below, the wires or rods can be tightened and the face boards made to hug the previous day's work, thus avoiding an unsightly lip and saggy contact which will deform otherwise good surface. If stopped 6 in. above the wires or rods, the weight of the concrete will tighten the wire and draw the wale close to the studs and thus bring the boards tight to face. Should the above precautions be neglected, it will necessitate shimming the boards away from the studs with shims. and just driving them out with a hammer. Unless the boards are shimmed, the wet concrete will force them back against the studs and the result will be an ugly finish.

Joints in Massive Walls.—When the concrete is subject to vertical forces only, as in foundations for buildings and masonry

structures, horizontal joints are less objectionable than vertical joints. But in the construction of concrete abutments, retaining walls and the like, vertical joints are desirable to confine the cracks to predetermined planes. In the building of such structures, the work should be divided into sections of such horizontal dimensions as may be thought best, and each section completed as a monolithic. There are several advantages in placing walls in short lengths at a time. Vertical joints do not show up as badly as horizontal ones, especially when these are made by the use of a bulkhead and are true to line as mentioned above. The contraction of the concrete due to setting will be somewhat equalized as the wall progresses, and these vertical joints will often be sufficient to take up expansion and contraction due to change in temperature. (See Art. 28.)

Walls should be stopped at horizontal or vertical bead or groove, so that the line at the junction of two days' work will not show. It is preferable to stop the wall in vertical planes across the wall, and, if practicable, the stoppage should occur at an expansion joint. This will sometimes require the continuous prosecution of work for 24 or 48 hours. Whether this method, involving work at night, which is always more expensive and usually less thorough, is justified by the end sought, depends, of course, upon the character of the structure. When the day's work must stop elsewhere than at an expansion joint, it must be essentially on a vertical line with a key or other positive form of bond provided for the connection of the subsequent work. This vertical stop-line must be stepped back at least one foot for other and subsequent days' work.

Grooves for Joining Future Work.—When the placing of the concrete is suspended, all necessary grooves for joining future work must be made before the concrete has had time to set. This may be accomplished by embedding pieces of plank in the top of the horizontal and vertical layers of concrete, to be removed after the concrete has set, leaving depressions. Beveling the edges of these planks will facilitate their removal. At such joints special care must be taken to tamp the concrete thoroughly, in order that it may be as dense and compact as at other places. (See page 331.)

REINFORCED CONCRETE BUILDINGS

When the concreting of a building cannot be made a continuous process from start to finish, as is often the case, care must be exercised in stopping off one day's work and in joining the next day's work to the break. In no case must the concrete be stopped before the full depth of the floor has been completed over the area of section for one day's work. Where work on a reinforced concrete beam or slab should be stopped at night, or at any time work is suspended, has been a question or matter of opinion among engineers for some time, some claiming it should be stopped in one place and some in another, but the following is recognized good practice.

Joints in Footings.—Footings should be cast to their full depth at one operation. Where it is necessary to make joints between different portions of the same footing, the surface should be roughened after tamping so as to provide a suitable clinch for adjoining concrete to be placed later and should be scrubbed with cement grout with a broom before placing other concrete. (See Art. 27.)

Joints in Columns.—Joints should be made in the columns flush with the lower side of the beams or girder, and should be at right angles to their surfaces. It is preferable to pour the columns some six or eight hours before the beams and girders so as to allow time for settlement and shrinkage. In all cases the pouring of concrete for a column should be a continuous operation to the line where beams join in. (See page 306.)

Joints in Slabs.—It is better to pour an entire floor at once, but if stops must be made in slabs, the concrete should be stopped in a vertical plane at right angles to the span, either (1) at midspan, or (2) over the center of the supporting beam or girder. The inspector should determine which method is preferable. Joints at any other points between the work of successive days should not be permitted. If, however, for any cause work must be stopped at other points than those stated, the fresh concrete and the hardened concrete must be bonded by one of the methods described in Art. 27. Some contractors prefer the joint to be made along the longitudinal center line of the beam or girder, but the author has avoided cracks by making joints where concrete on top is in compression. With the proper amount of steel over supports, however, there is not much danger of the slab cracking if the second method is employed. No horizontal joints should be allowed in slabs. Panels having girders supporting but one beam should have no stops parallel to beams. For such panels all stops should be parallel to girders and preferably at the center of beams. The joint in slabs should be made fairly square but as rough as possible. (See Fig. 24.)

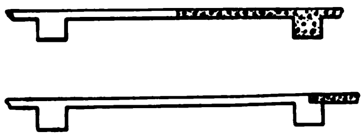

Fig. 24. Methods of Stopping Off Concrete Slabs.

Joints in Tile Floor Slabs.—The concrete for a tile floor slab with concrete over the top of the tile must all be poured at the same time.

Joints in Beams and Girders.—Girders or beams must never be constructed over freshly formed columns without allowing a period of at least three hours to elapse to permit settlement in the columns, preferably six or eight hours. Before resuming work the top of the column should be cleansed of foreign matter and laitance.

In beams or girders, the concrete should be stopped in a vertical plane at right angles to the length of the beam, either (1) at mid-span, or (2) over the center of the supporting column. The inspector should determine which method is preferable. Joints at any other points between the work of successive days should not be permitted. Where beams and girders are stopped off directly over the center of columns, vertical joints should be arranged so as to allow at least one-half the column for a bearing surface for the future work. The result of the practice of a number of contractors in stopping the concrete in the center of the span of a beam or girder has proved that this is the best place to stop the concrete. The concrete at this point being in compression and there being no shearing strain, and all tensile strain being taken by the reinforcement, there is less danger of a break or crack at this point than any other, hence it is the best point. (See Fig. 25.)

In no event should work be terminated in beams or girders where future shearing action becomes great, as at their ends or directly under a heavy concentrated load. Where brackets are used, the

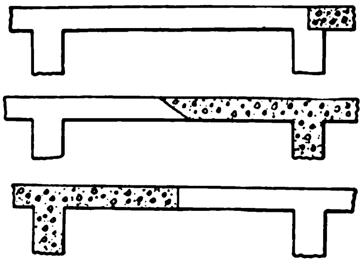

Fig. 25. Methods of Stopping Off Concrete Girders.

brackets should be considered as part of the beam or girder. As a rule, deep beams should be constructed some in advance of the slab, but no concrete should be placed in the beam and allowed to become so dry as not to properly bond with the balance of the work. Any concrete which may run past the bulkheads must be cleaned up before the concreting of the next section is started.

Where a beam and slab have been figured as a T-beam, both should invariably be poured at the same time. The inspector must not allow the beams and girders to be filled to the top of the slab centering and left in this manner. The stopping of the work must always be arranged so that the slab makes monolithic junction with the beams and girders at least for a distance equal to one-half their width. Where the beam has been figured as rectangular, it is not so important that both be placed at once; however, it is preferable to do so, as the full depth of beam includes a part of the slab. A notch may be left for the support of the slab, and thus nearly the entire beam would be placed at one time.

Beams and girders are sometimes split in two in the middle longitudinally, by means of a temporary vertical bulkhead, when it is

necessary to stop work in their neighborhood. Theoretically this is the place to stop the concrete of a beam, but the author does not recommend this practice by any means. It is much better to leave a step or notch the depth of the slab, an inch or two wide, at the top of the beam or girder. This step will act as a support for the slab, and if the beam is figured as a rectangular beam, as it should be, and not as a T-beam, it can depend to a considerable extent upon the other slab for what may be lacking in bond at the step. There is generally always an excess of compression area in beams designed to carry slabs. It is much more economical and just as good practice to rely upon this excess compression area in the adjoining slab than to go to the trouble and expense of placing a bulkhead along the center plane of a beam or girder, with all of the added difficulties this method entails; i. e., narrowing up the space to work in, possible displacing of the steel, different degrees of shrinkage contraction, additional time required, etc.

Joints in Flat Slab System.—In stopping, in all cases the column and column head should be cast and the splice or joint made up against a vertical plank in the center of a panel, the splice or joint being in a vertical plane.

Art. 27. Bonding New to Old Concrete

Bonding new to old concrete is a matter that requires the greatest care. Fresh concrete does not strongly adhere to concrete that has set. In fact, new and old concrete can be joined only with difficulty, and the strength of such a connection is always uncertain. When concrete is being laid there is always danger when part of the work has set, overnight, for instance, that the remainder of the work will not stick to the old part. Retaining walls will occasionally give evidence where one day's work ended and the next began, and frequently a crack will occur along this line. It is only with the greatest care that a cement finished coat can be made to adhere to a concrete base that has reached its final set (see page 410). The older and drier the concrete, the weaker the joint with the new.

In building tanks or other structures which must be water-tight, the surest way is to build the work as a monolith, i. e., without stopping the work; but with reasonable care a water-tight joint can be made by observing the precautions most applicable to such work as given in this article. In this connection see Art. 47.

Preliminary Precautions to Be Observed While Concreting.—Should the continuous laying of concrete be interrupted for any reason, care must be taken to see that the finishing surface is left so that the conditions of continuous work are approximated as near as possible. Concrete work to which it is intended to make additions should never be left smooth. In fact, it is always better to leave the surface rough than smooth.

Some Causes of Ineffective Bonds.—When the top of a wall is setting cement paste is forced up to the surface, and this sets and

becomes dead, the product being known as "laitance." (See page 342.) It is this laitance that makes the bonding of new to old concrete very difficult.

An almost invisible film of oil or grease, which often gets on the concrete from the forms, is very effective in preventing a bond, and is very difficult to remove. For this reason it is better to use soap than oil on the inside of the forms, since soap is soluble in cold water and hence is easily washed off. (See page 242.)

The greatest cause of the difficulty in bonding new concrete to old is dirt.

Joining New Concrete to Partially Set.—When one layer of concrete is to be deposited upon another partially set, precautions must be taken to secure a good union between the two, particularly if the joint is likely to be subjected to tensile or shearing stresses, or if the concrete is required to be water-tight. In joining new work to that which is partly set, such precautions of cleaning and wetting the surface and bonding should be observed as the engineer directs. If the first layer is only partially set, it is generally sufficient to simply wet the old concrete, taking care that no puddles of water are left upon its surface.

Joining New Concrete to Old.—Satisfactory means must be taken to clean and roughen the concrete which has set, and to secure a good and efficient bond between the older concrete and the fresh concrete placed above or against it. In other words, the bonding of new to old concrete must be made as good as the conditions will permit. Old and new work must be joined with some precaution.

Concrete which has set hard has a surface skin or glaze to which fresh concrete will not adhere strongly unless special effort is made to perfect the bond. Various ways of doing this are as follows:

METHODS OF BONDING NEW TO OLD CONCRETE

New concrete should be joined to old concrete only after the surface of the old concrete has been removed by mechanical or chemical means, and the rough surface made in this way thoroughly cleaned with scrubbing-brushes and water.

Preparing Surface.—When a course of fresh concrete is to be laid on a surface of concrete which has been exposed for several days or longer, the surface should be thoroughly cleaned of all foreign material and laitance or scum, and drenched with water (preferably under pressure), so as to make a firm bond between the two layers. It is very important that the surface be clean. The reason difficulty is experienced in making new work join to old is that not sufficient care is used in getting the old surfaces clean. The secret of securing a good bond between fresh concrete and concrete that has set lies largely in getting rid of the glazed skin and the slime and dust which form on it.

If necessary, the surface of the set concrete should be thoroughly rubbed with stiff wire or willow brooms, removing any loose stones

at the surface that appear to be loose. The brushing should be followed by washing to remove all loose chips and dust.

The surface may also be roughened with a pick, although this last operation is not always as beneficial as generally imagined. The picking should be followed by washing to remove all loose chips and dust.

Special care must be taken to remove all loose, inert or foreign material from the old concrete before any attempt at bonding the new work is made. If laitance has collected, it must be carefully and completely removed before the new material is added, in order to make a better bond. Also the forms should be cleaned of any concrete that has been spattered on them. Nothing is so bad for joints as sawdust, and nothing is so hard to get rid of. Shavings and blocks of wood may be picked up with rag-pickers' sticks, which are pieces of wood about 1 in. square having a sharpened nail driven into one end. Loose gravel, etc., can often be brushed out. Sawdust, however, remains. Even a strong stream of water fails to get rid of it. Live steam at a high pressure will, however, clean off the surface of the concrete to the bone. It removes all the half-set and dead cement and all the sawdust. Cleaning with steam is discussed below.

Do not allow any fresh concrete to be deposited on concrete that has been in place and set, until the surface of the concrete in place has been washed clean. Washing the old surface with a hose or scrubbing it with a brush and water improves the bond, as does also the hard tamping of the concrete immediately over the joint. In fact, in the opinion of the author, the thorough cleansing of the surface with water is more essential than a bonding coat of cement grout or mortar mentioned below. Keep a hose handy with plenty of water pressure and do not hesitate to use it freely for cleaning purposes.

Cleaning with Steam.—After the surface of the old concrete has been brushed as clean as possible with stiff brushes, it may then be gone over with a steam jet under high pressure. The steam will certainly clean off the concrete as nothing else will. The steam will leave the surface perfectly dry, so that it is important to drench the surface thoroughly with water afterwards. The new concrete should be placed immediately after the surface is cleaned and drenched. It is absolutely essential that the surface of the old concrete be drenched with water after using the steam jet. If the job is not large enough to justify using a steam jet, then use wire brushes and plenty of elbow grease, following with water applied through a hose. (See pages 339, 355 and 449.)

Cleaning with Acid.—Instead of using steam, the old concrete surface may be washed with a solution of hydrochloric (muriatic) acid, one part acid to two parts water, after which the surface must be carefully washed to remove any free acid. Any remaining traces of acid may be detected by tasting the water left on the surface. The surface of the hardened concrete may also be treated with a specially prepared acid wash, such as "Ransomite." This wash

must be thoroughly removed by washing with pure water. If reinforcing is used, do not use any acid, but do the best work possible to make a good joint without it. (See page 339.)

This is a very commonly applied method of cleaning old concrete surfaces preparatory to placing new concrete against them, and by many is considered the only safe one to use, especially where a "finish coat" is to be put on after the concrete base is set. (See pages 410, 425, 442 and 483.)

Wetting Surfaces.—After the old concrete surface has been thoroughly cleaned (either with brushes, steam or acid) of all loose material, laitance and dust, it must be thoroughly drenched, that the old concrete may not absorb water from the fresh concrete. A coat of cement grout over work or a first batch of mortar is a wise precaution, although not half as valuable as the use of plenty of water. It is imperative that old concrete be well soaked with water before new concrete is joined to it. If necessary, the old surface should be kept covered with water for several hours.

Cement Grout Coating.—The most common method of bonding new to old concrete is to clean the hardened surface from all loose material in a manner similar to that described above, and give it a thorough wash of cement grout, against which the fresh concrete is deposited and rammed before the grout has had time to set; but grout is somewhat uncertain in its action. In joining new and old layers together, too much care cannot be taken to have them well grouted as refilling proceeds; too much grout, however, should not be used, or the bedding will not be so good. The cement grout should be thoroughly brushed and tamped in with an ordinary broom, after which the new concrete may be placed. The care taken is of no avail if the cement grout is allowed to dry out or set before the new concrete is put on.

Neat Cement Coating.—Neat cement is sometimes sifted on the previously moistened surface and rubbed in with a broom. The author, however, does not recommend this practice. Grout is more satisfactory.

Cement Mortar Coating.—The bond may be strengthened by spreading a bed of 1:1 or 1:2 cement mortar, say, ½ in. thick on the prepared surface just before laying the fresh concrete. The mortar should not be leaner than 1 part Portland cement to 2 parts sand. The mortar should not be poured, but should be thrown on the surface with shovels, half a shovelful at a time. Then begin to deposit the concrete. If the joint is vertical and the mortar cannot be readily applied, use rods or spades or pieces of wood to work the mortar in the concrete up to the face of the joint and into the key. The first layer of the new concrete should contain a little more water than is customary to use for ordinary work. The care taken is of no avail if the mortar is allowed to dry out or set before the new concrete is put on.

There are some high-grade imported cements that in the form of cement mortar more readily adhere to old concrete work than the usual

Portland cements. These cements are frequently used for patching and piecing out work already in place. (See Art. 30.)

Retempered Mortar Coating.—Retempered mortar is sometimes used instead of the ordinary mortar coating as mentioned above. The retempered mortar is slow setting and interposes between the old, hard-set concrete and the new, quick-setting concrete, a layer of material that will join to both. It forms, as it were, an elastic joint during the time the new concrete is setting. (See page 166.) The addition of a small amount of lime prevents too great shrinkage in setting. Retempered mortar, therefore, with a slight amount of lime may be used as a material to interpose between old concrete surfaces and freshly deposited concrete to make a close junction.

Proprietary Compound Coatings.—There are several compounds on the market that are assumed to possess the quality of joining old concrete with new in a manner to give a strength equal to the mass of the concrete. These compounds, however, have been used with doubtful success. Comparative tests that have been made where such compounds have been used, and where junctions have been carefully made with new concrete, prove in most instances that they have little efficiency.

Asphalt Coating.—Where two or more sections completed on different days join, a hot asphalt or other bond approved by the engineer may be used between adjacent sections.

Use of Retempered Concrete.—In attempting to bond new concrete to that which has been set a long time, it is claimed to be an advantage to allow the new concrete to take an initial set and then add water and remix it before using.* The advantages claimed are: First, since concrete shrinks in hardening in air, allowing the concrete to take an initial set and then remixing it eliminates part of the ordinary shrinkage. Second, all concrete shrinks through cooling after the elevation of temperature due to the chemical action of setting, and the addition of water the second time cools the concrete and prevents at least part of the shrinkage due to this cause.

Use of Dry Mortar.—Sometimes a mixture of sand and cement (1 to 3) perfectly dry is poured over the top of a wall a few minutes before work stops, and puddled well, so that as the cement paste rises it mixes with this dry material and a semi-porous coating is formed on top which contains little or no dirt. When starting work the next morning a thin paste of cement and water is placed over the top, and then on this a cement mortar 1 or 2 in. thick. The concrete follows quickly, and the result is generally a first-class joint.

Layer of Broken Stone.—The surface of the concrete which is to be bonded to other concrete may be left in a rough condition by spreading a layer of broken stone or gravel over the same, ramming half the depth of the stone into the green concrete and leaving the upper half of the stone protruding. Large stones weighing a hundred pounds or more are frequently embedded one-half their depth in the next layer of a day's work to form a bond with the following layer. These should be deposited irregularly in the fresh concrete

* Baker's "Masonry Construction," 1909 edition, page 173.

and allowed to become firmly embedded, projecting somewhat irregularly above the upper surface of the mass concrete.

Metal Ties.—Sometimes short pieces of iron or steel projecting up from the old work are embedded; the new work grips to this metal, which thus forms a tie. If the old work is left very rough and irregular, it will probably not be necessary, except in extreme cases, to use metal ties. (See page 340.)

Old Rail Ends.—If for any reason the work has to be interrupted, a number of old rail ends set vertically may be partly embedded in the last layer so that the projecting ends will provide a grip for the succeeding layers. This should not be permitted, however, near the top of the work.

Cement Bags Filled with Sand.—On high core walls for earth dams, cement bags filled with sand are sometimes used instead of plank to make the end faces of each section of concrete. Such bags are piled up so as to make steps, each step being about 3 ft. high.

Bags Filled with Ice.—A novel method of bonding new concrete to old consists in placing bags of cracked ice on the last surfaces of concrete placed at night, thus reducing the temperature of the concrete, and consequently retarding its time of setting, so that on the next morning the surface is still plastic and the concrete then placed will set in one mass with the old. This method has worked very successfully for small work but to what extent it could be applied to heavier work is not as yet known.

Grooves and Rammer Holes.—The surface of the concrete which is to be bonded to other concrete may be left in a rough condition by setting in strips of timber, say, 4 or 6 in. square, which when removed will form a groove and assist in making a good bond. In other words, in order to bond the successive courses, horizontal channels running lengthwise of the wall at least two inches deep and four inches wide should be formed at the top of the upper layer of each day's work, and at such other levels as work is interrupted, until the concrete has taken its initial set.

Another method is to take a rammer about 4x4 in. and go over the soft concrete, forcing the rammer into it about 2 or 3 in. deep once to every foot of surface, thus making a number of holes or indentations in the soft concrete. The next layer of concrete will fill these indentations and dowel the two layers of concrete together. If the concrete used is too soft to hold the indentations made, a number of 6-in. wooden cubical blocks (or strips or timber, as mentioned above) can be embedded in the last layer laid and left in until ready to begin concreting again. Beveling the edges of these blocks or strips of timber will facilitate their removal.

To bond a vertical face of one section to that of the next, one or more uprights of, say, 6 or 8 in. square timber may be bedded in the concrete and removed before building the adjoining section; or a trough made of two 2x10-in. planks may be bedded with its open face against the plank forming the end of the section form.

Expansion Joints.—Where expansion joints occur, the faces of the old concrete, after being cleaned dry, should be given a heavy

coat of crude oil, which should have at least one day's drying before fresh concrete is laid against it. (See Art. 28.)

Ramming Layers of New Concrete.—Care must be taken to especially and vigorously ram the first new layer of concrete and the ramming continued so that a dense concrete will result, with perfect bonding between the several layers. These layers must be made with great care and in a manner satisfactory to the engineer. (See page 299.) As a rule, a good enough joint for ordinary purposes can be got by tamping the fresh concrete directly against the old concrete, without grout or mortar coating as mentioned above, if the surface of the latter is thoroughly cleaned by scrubbing and flushing.

Failure of Concrete to Bond or Set.—Any concrete that fails to show proper bond, or that fails to set after it has been allowed sufficient time, should be taken up and replaced with new concrete of proper quality.

Thin Edges of Mortar.—Thin edges of mortar that have run out over the center or bottom of forms should be broken up into small pieces and allowed to become embedded in new work.

Art. 28. Contraction Joints

Temperature changes and shrinkage during setting necessitate joints at frequent intervals, or else effective reinforcement, depending upon the range in temperature and the design of the structure. The causes of expansion apart from the changes of temperature are not fully known, but, generally speaking, a cement used too fresh tends to expand. Expansion joints should be provided at all points where temperature changes would otherwise cause unsightly cracks. In all cases joints should be at right angles to their surfaces, and should be constructed exactly according to the engineer's plans. Contraction joints are difficult to make in work designed to be impervious, and require exceptional care in their construction. Expansion joints should always be provided in flat surfaces, likewise sidewalks or floors. (See Art. 51, page 478.)

Massive Concrete Walls.—Expansion joints are very necessary in walls of large sectional area and considerable length. Undoubtedly many of the cracks which one observes in long walls of concrete would not have occurred had there been a careful distribution of expansion joints, which really locate the cracks to predetermined positions.

In massive concrete work, such as retaining walls, abutments, etc., built without reinforcement, joints should be provided approximately every 30 ft. throughout the length of the structure. To provide against the structure being thrown out of line by unequal settlement, each section of the wall may be tongued and grooved into the adjoining section. Each section should be finished from the footing course to the top before the adjoining section is started, and no attempt should be made to make the sections adhere to each other, so that when cold contracts the structure it will open up

slightly in these vertical joints and not in an irregular crack. A dowel contraction joint may be used instead of a tongue-and-grooved joint.

Reinforced Concrete Walls.—In reinforced concrete walls the expansion joints should be spaced about fifty (50) feet apart, unless otherwise called for or shown by the plans.

Forming Ordinary Joints.—In ordinary short walls the joint may be made by setting up a temporary vertical form or partition of plank and completing the section behind as though it were the end of the structure. When the concrete is set the partition is removed and the new concrete is placed against the old, without any attempt to secure a bond between the new and the old, thus leaving a vertical plane of cleavage between the adjacent sections. In order to cover up the ragged appearance of the joint, the author would suggest that a triangular strip be nailed to the form where the partition joins the face of the form in such a manner as to leave a vertical triangular groove in the face of the wall with the plane of the contraction joint passing through the apex. A heavy coat of asphalt or coal tar pitch, applied hot to the surface of the section of concrete which was first placed, may be used to prevent a possible adhesion of the new to the old concrete. A sheet of tarred paper may also be used. (See page 503.)

Forming Tongue-and-Grooved Joints.—There should be spiked vertically to the face of the temporary partition or bulkhead a triangular or rectangular or U-shaped timber against which the concrete is to be rammed, so that a depression will be formed in the end of the section, giving the effect of tongue-and-grooved joints in the finished wall. The advantage of the tongue-and-grooved joint over the ordinary joint as mentioned above is to strengthen the wall against a lateral thrust applied near the joint.

Forming Dowel Joints.—A dowel contraction joint is made by inserting a short piece of railroad rail in the end of a section of a retaining wall and allowing the rail to project a short distance. Care must be taken to see that the projecting ends of the rails are well wrapped with paper or coated with soap or axle grease, in order to prevent the adhesion of concrete when the adjoining section is placed. Otherwise the concrete laid in the last section will not be free to slip on the rails with temperature changes. (See also Art. 18, page 239.)

Art. 29. Protection of Concrete after Placing

Concrete should not be disturbed more than absolutely necessary after being put in place. It is useless to make good concrete unless care is taken to protect it until it is hard enough to take care of itself. The setting of the concrete is greatly influenced by atmospheric conditions. Hot weather accelerates the action, and cold weather retards it. Otherwise, neither heat nor cold need have any injurious action on the concrete if proper precautions are taken. Until sufficient hardening of the concrete has occurred, the struc-

tural parts must be protected against the effect of freezing and premature drying, as well as against vibrations and loads. These precautions are indispensable. (See also page 460.)

Concrete Deposited in Wet Places.—Concrete required to be deposited in wet places should be thoroughly protected so that the cement will not wash out. (See Art. 36.) No water should be allowed to stand on or to flow over fresh concrete work until the work has had time to set.

Jarring of Concrete.—After the concrete is placed it must be left undisturbed until it has received a hard set. To this end care must be taken in placing concrete beside other concrete that is partially set, so as not to undo previous work. Jarring the projecting ends of steel reinforcement with buckets, wheelbarrows or carts in placing fresh concrete will impair the bond of work that is partially set. Jarring the forms by the buckets or carts in which the concrete is handled will give the same results. The jar of a hoisting engine and concrete mixer or other moving machinery should not be allowed to reach the setting concrete. The concrete work must not be subjected to sudden shock by dropping lumber, in the storing of false-work, upon it.

In the placing of concrete in girders and floor systems it is quite a common procedure to start near the hoisting tower and work toward the opposite side of the building, in which case concrete placed in the early part of the day, and having received an initial set, is subjected to the continuous passage of wheelbarrows heavily loaded and roughly handled over runways of single planking unevenly laid, and with no regard whatever for deflections and vibrations which will be produced in the freshly laid floor. These deflections and vibrations are often quite considerable, as the rigidity is only that offered by the supporting forms (see page 212). The author has seen a panel of floor, after having been subjected to the vibrations and shocks due to about one thousand loaded wheelbarrows and two thousand men passing over it before it was ten hours old, with cracks extending at right angles to the reinforcement so large that they were noticeable in the light of an arc lamp. And on the following day, when the concrete had a good firm set, these same cracks were fully as noticeable.

In placing the concrete the work should be so laid out that partly set concrete will not be subjected to shocks from men wheeling or handling material over it. In fact, the distribution of concrete must be so arranged as to reduce to a minimum all traffic and wheelbarrows over actual finished work. This may be avoided to some extent by planning the work so that concrete farthest from the mixer will be deposited first. Where concrete that is setting has to be worked on in order to carry on the operation, planks should be laid on small horses in such manner that the finished concrete is not disturbed in wheeling or walking over it.

Walking over newly-laid concrete should be avoided as much as possible. If walked on or wheeled over during the time of setting, the set will be incomplete, or may be entirely destroyed. Concrete

should be allowed to set for 24 hours, or more, if so directed, before any work shall be laid upon it or any walking allowed upon it. Walking across a concrete floor before the hardening is sufficiently advanced will cause rotten places in the concrete, if not permanent injury. Workmen are likely to pay little attention to this, and constant watching on the part of the inspector is necessary to guard against it. Workmen who persist in walking on green concrete should be discharged.

Protection from Sun and Wind.—Exposed surfaces of freshly placed concrete should be shaded to protect them from rain, dust, wind and the hot rays of the sun, by boards or tarpaulins. Protection of concrete from too rapid drying is important, especially in the case of narrow sections and reinforced work. When work is delayed for any reason the upper exposed surface should be protected by a canvas cover until the work proceeds. If the concrete surface has been badly hair-checked from heat the defect can usually be remedied by rubbing with a carborundum brick as described on page 400. (See page 490.)

Keeping Concrete Moist.—After concrete has been placed, a very important detail is to keep it constantly wet until it is covered over with whatever material is to come on it. In a way, the successful making of hay and concrete is very much alike—both must be well cured. It is a common thing to find experienced foremen who fully believe that concrete should "dry out," and many pieces of otherwise good concrete have been rendered worthless by acting upon this idea, which ignores the plain fact that "hydraulic" cement requires water. In other words, care must be taken to prevent concrete from drying too rapidly, especially in hot weather (see page 348).

To enable the concrete to set properly it must be kept moist. This is an item which too often is neglected, especially in rush work, and which prevents many otherwise well-designed reinforced concrete constructions from attaining the strength intended. Keeping the concrete wet prevents to a large degree contraction in hardening. All exposed surfaces of finished and unfinished concrete should be kept constantly moist by sprinkling with clean water at short intervals, unless otherwise directed during cold weather, or by covering with moistened burlap, or by such other means as may be approved. This moistening should continue until the permanent covering is in place, or until the concrete has sufficiently hardened. Wetting should commence as soon as the surface of the concrete has set. Failure to observe some such precaution is almost certain to result in a weakening of the concrete, due to the setting up of distortionate hardening stresses, and especially in hot, dry weather is the danger real, the outer crust being then oftentimes seriously damaged as mentioned on page 380.

The surface of concrete exposed to premature drying should be kept wet for a period of at least seven days, and the longer thereafter, the better. This may be done by a covering of wet sand or sawdust, burlap, or by continuous sprinkling, or by some other method equally effective. An excellent practice is to cover the surface

with burlaps, which may be kept saturated, as this not only furnishes the necessary moisture but protects the work from the direct rays of the sun. The interior of a large mass of concrete work will probably take care of itself by keeping the burlap wetted down by means of a hose, but the precaution has sometimes been taken of leaving vertical holes or wells in the mass, which are kept filled with water for some weeks and are then filled with concrete.

Another very satisfactory method is to cover the fresh concrete surface, as soon as it is hard enough to bear it, with a layer of wet sand, say, an inch thick. This retains moisture excellently, thereby nicely wet-blanketing the concrete and feeding it with water as soon as it so requires. Attesting the benefit of wet sand, concrete cubes for testing purposes, molded in sand and kept moistened until tested at the end of a month, showed percentages of increase in crushing strength as high as 50 per cent. A layer of moist sawdust will answer as well as the moist sand. Layers of sand or sawdust are applicable only to horizontal or nearly horizontal surface. Vertical surfaces should be kept wet by sprinkling, or, if the surfaces are exposed to the sun, should be covered with canvas and kept wetted down as described above.

Concrete laid in warm weather should be drenched with water twice daily, Sunday included, during the first week after being put in place. Throughout the work care must be taken to prevent the rapid drying of the concrete by the sun. Some specifications require that concrete be well sprinkled in hot weather every two hours of the first day and at longer intervals during the several succeeding days. The inspector will, of course, be governed by the engineer's directions in this regard. Portland cement requires a large amount of water to form its crystals. You can't keep it too wet; the more water, the better.

Plumbing and Leveling of Forms.—No work should be done upon forms, nor should they be moved in any way after the concrete is in place, except to correct or secure them before the concrete has set. (See pages 211, 218 and 231.)

Protection from Blasting.—Sufficient canvas or timber covering must be provided to protect freshly-laid work from blasting.

Protection from Traffic.—Where traffic is unavoidable over green concrete, the surface should be covered with at least 3 in. of sand for protection, or suitable boards should be provided for the purpose of distributing the weights. If possible, keep newly laid concrete free from traffic of any kind for two or three days. (See page 491.)

Protection from Frost.—Fresh concrete should be covered to protect it from danger of injury by frost. Much more serious is the action of frost, and especially of repeated freezing and thawing; the precautions to be taken in the summer, as mentioned above, are simple compared with those required in winter, where the weather may suddenly change from mild to bitter cold. For protection of concrete laid in freezing weather, see page 360. If the concrete has been frost-pitted, on the surface only, bush hammering will give a rough stone finish, pleasing in appearance. (See page 403.)

Time to Set (Heavy Loads).—After the concrete has begun to set it should not be disturbed until it has hardened sufficiently to bear easily any weight that may be put upon it. Time must be given for concrete to become firm before masonry foundation or other mass work is commenced upon it, usually as much as 24 hours, as heavy pressure tends to retard the setting. In the case of quick-setting natural cements, however, 12 hours may be sufficient.

Protecting Finished Work.—All concrete ledges likely to be broken off by falling or other objects should be protected from injury. (See also pages 289, 294, 403 and 460.)

Formwork should be allowed to remain around the members or structure as long as possible, as this lessens the danger of accident (see Art. 19), sagging horizontal members and of the breaking off of prominent corners and edges or of otherwise marring the work while it is green.

Cutting of Reinforced Concrete Floors.—The reinforced concrete work should not be cut or drilled for the installation of pipes, electric wiring or other work without the permission of the engineer in charge of the work. In no instance should the concrete be cut away from the bottom of beams or girders or holes drilled in the concrete work at these points. With permission, holes can be drilled in the sides of concrete beams and girders, 6 in. above the soffit, and holes may be cut through floor slab, provided the work is executed in such a manner as not to spall or damage the concrete work seriously. But drilling into the bottoms of beams and girders, or into the sides of hooped or spiral columns, should not be allowed when avoidable. It is quite often possible to confine the drilling to the slabs and the sides of the beams and girders.

When cutting or drilling holes in structural concrete of any kind, the lighter hammers and chisels should be used in preference to the heavy tools, and many light blows rather than a few heavy ones should be insisted upon, for the reason that heavy blows have considerable shattering effect on the concrete, especially in the first few weeks after pouring. Hence the pneumatic drill is to be preferred where obtainable, especially when putting in new bolt holes, etc., in great numbers.

Art. 30. Patching and Repairing Defective Concrete Surfaces

The concrete gang, and especially its foreman, should be made to understand that it is their duty to make concrete which will not require after-treatment to make up for their carelessness or haste. This would eliminate many of the causes of failure in concrete work, and at the same time tend to secure better and more careful work, even from the irresponsible ordinary laborers employed in this connection. It ought not to be necessary on first-class work to be continually patching up. Arrises and corners can not be patched up except by cutting out large sections of the work. Plastering which is put on finished work will not hold unless it is put in very thin

layers, and then it is doubtful (see page 410). Corners can never be satisfactorily patched up by plastering.

Defective Spots in Beams, Girders, Etc.—It is customary to have all defective spots in beams, girders, slabs, columns, etc., patched as soon as the forms are removed, in order to cover up those defects caused by careless workmen or by chance, which it seems almost impossible to eliminate where exposed surfaces are concerned and a very smooth job is required. But it has happened too many times that when, upon the removal of forms, the under side of beams showed spots where the concrete failed to surround the reinforcing rods, they were patched immediately, thus making it impossible to tell just how bad the defect was, as the exterior showed only the surface of the patched spot.

Inspection of Defective Work.—When concrete work is stripped of its forms, absolutely no patching or plastering should be done on it until the work has been passed upon by a competent inspector. Structural weaknesses might be covered up and never detected if cases of this kind were not properly examined as mentioned above. Furthermore, those places that need patching or plastering are the best indication of the general character of the hidden work. If every superintendent, foreman and other workman realized that no patching could be done until the spots needing it had been thoroughly examined and inspected, the result would be more careful work and the elimination of a most fruitful source of failure. It cannot be too strongly emphasized that no patching up shall ever be done until the work has been carefully inspected. The author firmly believes that a rule to the effect that no patching of reinforced concrete be done until the work has been inspected by a duly authorized city inspector ought to be embodied in municipal building codes. The positive enforcement of this rule will be accompanied by better results generally.

Patched work is generally detectable, being of a slightly different color than the body of the work and often is accompanied with shrinkage cracks around the patch.

Workmanship.—Where concrete is properly deposited and manipulated along the face of the structure, less than a quart of cement should be required to remedy any defects in appearance.

METHODS OF PATCHING AND REPAIRING CONCRETE

After forms are removed, any surfaces in the concrete not properly filled should be gone over with cement mortar and finished with a wood or cork float, rubbed with stone, chipped, stuccoed, or some other manner. In other words, all concrete that is spalled or honeycombed should be neatly patched with cement mortar. If appearance is an object, all projections must be removed by chiseling or bush hammering. (See pages 403 and 405.)

Commonly when a concrete surface is to be patched a sand and cement mortar is made, some cutting is done and the mortar is put in and scrubbed with a steel trowel until smooth. It is then covered up for awhile. If the concrete under the patch is left dry it soaks

up the water of the mortar. As a result, the mortar does not set. If the weather is dry or hot the surface of the patch dries out and for the same reason it does not set. If the concrete under the patch is dusty the patch does not adhere to the concrete. A careful observance of the following instructions will correct these defects.

Cleaning Surface.—In all cases the surface to be repaired must first be thoroughly cleaned of all loose material, laitance and dust, and the clean, rough, sound concrete exposed to receive the patch. (See page 327.) All pitting must be brushed out with steel brushes until the surface is rough. Probably the best method of cleaning is by means of a steam jet.

Cleaning with Steam.—This is a method of cleaning surfaces of old concrete preparatory to putting on a patch of new, or of cleaning the top of a rough concrete floor before applying the "finish coat." (See page 328.) The surface of the old concrete should be brushed as clean as possible with stiff brushes and then gone over at least twice with a steam jet—an ordinary piece of ½-in. gas pipe makes a very satisfactory jet nozzle. A short length of pipe should be connected to a steam hose so that it can be readily moved about. Steam is generally supplied by the boilers of the mixer or hoisting engines. Steam will clean and heat the concrete surface, leaving it perfectly dry, so it is important to thoroughly drench the surface with water after cleaning with steam. In cold weather it is found advantageous to use hot water. (See page 355.)

Excellent results have followed the use of this method of cleaning, but it is absolutely essential that the surface of the old concrete be thoroughly drenched with water after using the steam jet, otherwise the mortar patch will not adhere to the old concrete.

Cleaning with Acid.—This method includes washing of the surface of the old concrete with a solution of hydrochloric (muriatic) acid (one part acid to two parts water), after which the surface must be carefully and thoroughly washed to remove any free acid. (See pages 328 and 402.)

This is a very commonly applied method of cleaning old concrete surfaces preparatory to placing new concrete against them, and by many is considered the only safe one to use, especially where a "finish coat" is to be put on after the concrete has set. (See page 483.)

Wetting Surfaces.—After cleaning, the surface to be repaired must be thoroughly saturated with water, not simply moistened, but so thoroughly drenched that the old concrete will not absorb water from the mortar used in patching. If possible, the surface should be kept covered with water for several hours. (See page 329.)

Moderately Dry Method (Vertical or Sloping Surfaces).—If the repair or patch is to be made on a vertical or sloping surface, and is not to be more than 1½ in. thick, the surface of the old concrete, while still wet, should be spattered or splashed with a cement grout (or powdered with neat cement), following this immediately with a fairly stiff plaster coat of mortar made of the same proportions of cement and sand as were used in the original concrete, but never

richer than 1 cement to 2 sand. This plaster coat should not be thicker than ½ in., and each coat should be forced into the surface, but not dragged with a trowel. The surface of each coat, except the final coat, should be "scratched" to give a bond for the next coat. This plastering should preferably begin at the top and progress downward, and only enough time be allowed to permit each coat to receive its initial set before the next coat is applied. The final coat should be floated with a wooden float to the level of the surrounding concrete. This patch should be kept damp and protected from sun or frost until fully set up. Generally, such patches are kept moist by sprinkling them with water for several days. (See page 335.)

Wet Method (Horizontal or Nearly Horizontal Surfaces).—If the repair or patch or "finish coat" is to be made on a horizontal or nearly horizontal surface, the surface of the old concrete should be slushed and broomed with a thin cement grout, following immediately with a wet mortar made of 1 part of cement and 2½ parts sand or granite screenings, and of the full thickness required (not less than ¾ in. thick, however). When this mortar begins to take its initial set it should be floated or troweled to such a finish as may be desired. (See page 484.)

Dowel Method (Vertical or Sloping Surfaces).—If the repair or patch is to be made on a vertical or sloping surface, and is to be more than 1½ in. thick, it will be advisable to embed dowels into the old concrete, as deeply as the thickness of the proposed patch, and spaced sufficiently close together to firmly anchor the patch to the old concrete. The dowels must be wedged into the old concrete, and it will be advisable to fasten wires, metal fabric or bars to the dowels, in the case of extensive patching, as an additional safeguard. The patching may be done with mortar without forms, or with wet concrete supported by forms, depending upon the thickness and the extent of the patch. (See page 412.)

This method can be made uniformly successful, but cannot always be applied. Where any considerable mass of new concrete is to be connected to old concrete, this is the only safe method to pursue. (See page 331.)

Reinforcing Fabric Method (Horizontal or Nearly Horizontal Surfaces).—If the repair or patch is to be made on a horizontal or nearly horizontal surface, and of considerable thickness, dowels may be used, or the concrete may simply be reinforced by fabric or bars, without using dowels—treating the patch as a block of masonry.

Wedge Method (Horizontal or Vertical Surfaces).—Care must be taken not to have thin edges on patches. To avoid this, it may be necessary to cut out sound concrete around a place to be patched, so as to give deep edges to the patch. If possible, the edges should be undercut, so that the new concrete will be held in place, when set, by the shape of the binding edges of the old concrete.

The difficulty of undercutting concrete so as to secure such edges is too great to make this method applicable where a considerable depth of new concrete is to be put in.

Patching Concrete Floors.—When a cement floor surface begins to

wear it is often desirable to patch it and the way in which this can be done will now be discussed.

Cut down the worn place at least 1½ in. This cutting should be carried into the strong unbroken concrete and the edges should be cleanly undercut as mentioned above for the wedge method of patching concrete surfaces in general. The bottom of the cut should then be swept out, clean-blown out with compressed air, or a pair of bellows, if available or by means of a steam jet as mentioned on page 339 then thoroughly wet and scrubbed with a broom. In this way small loose particles of broken material which the chisel has driven into the surface are removed. A grout made of pure cement and water about the consistency of thin cream should be scrubbed into the pores with a broom or brush, both at the bottom and sides of the cut. Following this a stiffer grout about the consistency of soft putty should be thoroughly compressed and worked into the surface, which has already been spread with grout. Finally, before the grout is set, a mortar made of one part cement to one and one-half or two parts crushed stone or gravel, consisting of graded sizes from ⅜-in. or ½-in. down to the smallest excluding dust, should be thoroughly mixed and put in place, then floated to a proper surface. Cover with wet bagging, wet sand, sawdust, or other available material. All trucking should be kept off and the surface kept thoroughly wet for at least one week or ten days.

If a particularly hard surface is required, 6-penny nails may be mixed with the mortar and other nails stuck into the surface when the patch is finished. This will produce a surface which is extremely hard and durable.

Repairing Broken Corners.—Broken corners should be carefully repaired by thoroughly cleaning the surface, wetting the patch down well, then if possible driving 20-penny nails or railroad spikes into the concrete, putting up a form and grouting the broken place.

Precautions.—Do not point up with a mortar richer than the mortar used in the matrix of the concrete, for cracks will appear around the edges of the patch, besides which the color will be different. That is to say, the mortar used in patching should have the *same* proportions of cement and sand as the original concrete.

The less the mortar patch is rubbed, the less hair cracking will result. It takes a good deal of rubbing to get any results, and too much rubbing generally results in hair cracking as excess cement is worked to the surface.

A more uniform appearance to the work will be obtained if the pointed portions receive the imprint of a piece of board, which will leave the mark of the grain of the wood similar to the marks left by the forms, instead of the mark of the trowel.

Patches on concrete surfaces may be lightened to make their color the same as the original work by adding a small quantity of lime paste.

Frozen Concrete.—Any concrete which has been frozen or frost-bitten should be promptly removed and repaired as directed by the engineer. (See page 365.)

Art. 31. Efflorescence on Concrete Surfaces

Efflorescence is the term applied to the whitish or yellowish accumulations or stains which often appear on concrete surfaces exposed to the action of the weather. "Whitewash" is another name given to these blotches. This whitish scum sometimes appearing on concrete work if due to the leeching out of lime or other soluble chemical salts, is termed "efflorescence." But if the scum is due to excess of cement it is known as "laitance." The white efflorescence sometimes seen defacing concrete is not permanent or serious, and is easily removed by scrubbing with broom and water. Efflorescence does not mar simple details nearly as much as it does ornate ones.

APPEARANCE OF EFFLORESCENCE

Efflorescence is very erratic in its appearance. Some concretes never exhibit it; in some it may not appear for several years, and in others it shows soon after construction, and may appear in great quantities. In fact, the efflorescence may appear soon after the wall is built, or it may be that a long period will pass before this action takes place.

Wet Weather.—Efflorescence usually appears after a long wet spell when the concrete has been exposed to much water or dampness.

Horizontal Joints.—Efflorescence is particularly noticeable just below the horizontal joints in concrete walls, that is, just below the line between two successive days' work. For example, where a section of concrete retaining wall is first built, and a day or more afterwards a concrete coping is placed upon the wall, there is almost sure to be an unsightly white or yellow stain formed just below the coping. In other words, the most common place for efflorescence to appear in walls is at the horizontal junction of two days' work or where a coping is placed after the main body of the wall has been completed. It is most troublesome at horizontal joints where new work is placed on concrete that has already set. A close examination of these joints shows its appearance in the form of a very thin layer, of a soapy consistency. While efflorescences are most pronounced below copings, and wherever horizontal joints occur in concrete, they are not confined to such places, but frequently appear upon the face of a wall that has been built without horizontal joints, due to stopping of work at night, and which has been puddled in and not tamped in layers. In monolithic work efflorescence takes place on vertical or inclined surfaces most frequently at the plane of junction of old with new.

CAUSES OF EFFLORESCENCE

Efflorescence on concrete surfaces may be due to certain salts or soluble substances leaching out of the concrete and accumulating into thin layers after the water has evaporated. The absorption of water from the atmosphere may also account for this deposit in some degree, especially near the sea. Where new work is joined

to old there is an excess of cement at the joint, which makes it much more waterproof than the body of the wall. Water percolating through the wall washes out the above-named soapy material at this joint, thus causing efflorescence. Whether the efflorescence is due to one or the other of these causes, the action and the results are the same. The real cause of the deposition of this incrustation is not positively known, but it may probably be explained in one of the following two ways:

Loss of Cement.—Where concrete is laid "dry" and rammed, or where it is laid "wet" and puddled, the horizontal surface of the finished concrete layer consists of a mortar richer in cement than the body of the wall. Even if it is not richer at the time the concrete is left to set, it is usually made richer when a day or so later a sprinkling of neat cement is placed upon the surface to act as a binder for the next layer. The most finely pulverized portion of the cement fails to be acted upon chemically by the water, the cement remaining inert and afterwards being washed to the surface, where it is deposited and there forms an unsightly incrustation. This deposit is at first white, and afterwards turns yellow. This action is not unlike that which takes place in concrete deposited under water. As concrete is placed in water, a light colored, powdery substance is held in suspension by the water and is usually called "laitance." (See Art. 36, page 372.) When a concrete is mixed very wet the same action usually occurs. Analysis of this laitance shows a composition agreeing very closely with that of cement, and it must be inferred that the laitance represents an actual loss of cement.

Soluble Salts in the Cement or Concrete.—The use of "wet" or "sloppy" concrete appears to have resulted in greater amounts of efflorescence than was formerly seen when "dry" concrete was in fashion. But regardless of the amount of water in concrete at the time of its deposition, efflorescence, more or less pronounced, is quite certain to appear after a period of wet weather, owing to the saturation of the face of the concrete with water, which dissolves the soluble salts in the concrete and later deposits them upon the face of the wall. In other words, if the surface of the concrete becomes saturated to a depth of a few inches, and if soluble salts exist in the concrete (as they generally do), these salts will ultimately saturate the water and will be deposited upon the concrete surface, due to the more rapid evaporation of the water there and due to the lower temperature at the surface. Since solubility decreases with decrease in temperature, and since the force of osmosis causes a flow of the solution from parts of the concrete containing a stronger solution to parts containing a weaker, it follows that the face of a moist wall may be fed with soluble salts until all the salts are leached out of the wall.

It has been observed that efflorescence rarely occurs when certain brands of cement are used. and when others are employed it is much more apt to appear. It seems probable that in many cases the

trouble is caused by the presence of certain ingredients in the cement, probably sulphates of calcium and magnesium, both of which are contained in many cements and both of which are slightly soluble in water. Cements containing much sulphate of calcium and magnesium are more liable to show an efflorescence than those containing little of the above sulphates. These sulphates are soluble in water, and when the wall is soaked they are dissolved and carried to the surface, where they are deposited in a crystalline form when the water evaporates.

Different cements contain different proportions of soluble salts, and hence give different amounts of efflorescence. A careful chemical investigation of various cements which do and do not effloresce would doubtless prove of great value in this connection. Sulphate of calcium is somewhat of a harmful deposit, which may be supplied by the filtrating water or may come from the cement as mentioned above, either from the addition of gypsum or from the fuel used in burning. The crystallization of this salt in the pores of the concrete at the surface may cause disintegration. On the other hand, efflorescence may be quite harmless, as when it is formed by washing out from the mortar an excess of hydrate of lime. A portion of the latter may then be changed to carbonate of lime near the surface of the wall and actually stop up the pores or voids, and prevent further filtration.

As stated above, efflorescence on concrete surfaces is caused by the carriage by moisture of soluble salts or substances in the cement as in the aggregates to the surface, where the evaporation of the water leaves the substance. If there is too little water in the concrete when it is deposited, complete combination does not occur in the cement, the concrete is likely to be somewhat porous and subsequent moisture from any source has an opportunity to bring the soluble salts to the surface. When too much water is used it may separate the lime from the other ingredients in the cement to some extent, and when it evaporates it leaves the concrete somewhat porous and brings soluble matters to the surface.

The most common place for efflorescence to appear in walls is at the horizontal junction of two days' work or where a coping is placed after the main body of the wall has been completed. The reason of this seems to be that the salt solutions seep down through the concrete until they strike the nearly impervious film of cement that forms on the top surface of the old concrete before the new is added, and then they follow along this impervious film to the face of the wall. In other words, a slight skin of dense mortar forms on the upper surface of the concrete during tamping, which makes a comparatively water-tight layer. Water seeping into concrete from the rear or from above works its way to the outer surface at this impervious layer and deposits the soluble salts, which it has brought with it, upon the surface of the concrete as it evaporates.

Color of Efflorescence.—Efflorescence varies in color according to the material causing it. White color may be due to sulphates of

soda, lime, or magnesia or bisulphuret of iron. Yellow color is produced by the action of vegetable micro-organisms. Green color is caused by soluble variadiate salts.

Sodium Chloride or Common Salt.—Concrete to which common salt has been added to prevent freezing during cold weather is very liable to show efflorescence. (See Art. 33, page 351.)

Improper Manipulation of Concrete Work.—Efflorescence usually occurs in irregular patches, since in even the best work different portions of the concrete have different densities owing to their being richer, or containing more or less water, or being tamped more or less severely.

PREVENTION OF EFFLORESCENCE

The causes of efflorescence as mentioned above should be carefully studied in order that methods of prevention or cure may be intelligently considered. Efflorescence is its own cure if a sufficient amount of the soluble matter in the concrete is brought to the surface to close the pores or voids and make the mass waterproof, but removal of the deposit by rain or other causes prevents this action and the efflorescence will continue to some extent until the soluble matter is all brought out, unless proper means are taken to prevent this disfigurement. There are three methods of preventing or at least of decreasing efflorescence, which have been tried with more or less success, and are as follows:

Cement Containing Little or No Soluble Salts.—To prevent the formation of efflorescence the most effective method would be to use cement entirely free from soluble salts. There are cements upon the market which are almost entirely free from soluble salts (sulphates and chlorides), and which will cause little or no efflorescence. The likelihood of engineers resorting to the trouble of selecting such cements, however, except in rare instances, is not great, even if they knew what cements to select, so that other means must be sought. Perhaps it will be sufficient simply to use a face mortar made of a cement free from soluble salts and made rich so as to prevent percolation of water into the body of the wall.

Use of Inclined Layers.—The concrete may be laid fairly dry and deposited in layers having a slight slope, particularly the last one laid each day, toward the back of the wall, so that the drainage will be carried away from the face, and all objectionable incrustation be deposited on the back. This remedy is not applicable with wet or at least with sloppy concrete, unless the last concrete laid at night is mixed drier to permit of thus sloping the surface. If the back of the wall is stepped, as is common in bridge abutments and retaining walls, the top of the step should be given a flat downward slope away from the body of the wall, to prevent pools of water from standing on the top of the step and soaking into the body of the concrete. This may be rendered doubly effective by treating the face of the wall with a wash for rendering it impervious, such as mentioned in Art. 49. Inclining the layers toward the rear of the wall may be in itself a sufficient protection against leaching of the

soluble salts in the concrete under ordinary conditions. Sometimes, in addition to building the layers on a slight slope toward the rear of the wall, every other layer is well sprinkled with neat cement, so that all water moving by gravity in the body of the wall will be diverted toward its rear face. The top surface of each layer should be scrubbed with wire brushes and flushed with hose before the new concrete is placed.

Waterproofing Concrete Work.—The prevention of efflorescence seems to lie in the direction of more impervious concrete, not too wet mixtures, well puddled, with great care exercised at joints and in depositing materials so as to preclude superficial cracks even of minute size. The more nearly waterproof the concrete the less efflorescence will show on the surface. In other words, make the concrete waterproof, since if the water is kept out it will not dissolve the salts, and consequently efflorescence will be prevented. For a discussion of the several ways of making concrete impervious see Chap. VIII, page 421. By the use of one of the methods used to make concrete impervious—by the addition of alum and soap to the mixture—the efflorescence can be effectually prevented.

In Gillmore's "Lime, Hydraulic Cements and Mortar," it is stated that if about 10 lbs. of any cheap animal fat is well mixed with 100 lbs. of quick lime, which is afterwards slaked and mixed with a barrel of cement, the formation of efflorescence will be largely reduced, though not entirely prevented. The object of the fat being to saponify the alkaline substance, the lime forms a paste serving only as a vehicle for the fat.

Efflorescence can be prevented by waterproofing the exterior surface of the wall after the concrete has hardened. A method that is sure to be effective, for a time at least, is to use a Sylvester facing mortar (see page 443) or to apply a Sylvester wash of alum and soft soap to the face (see page 437). "Szerelmey stone liquid," when applied to the face of concrete, is said to make it perfectly impervious. A waterproof wash may be applied to walls made of very wet concrete, the wash preventing the escape of the efflorescence to the face of the wall. Other similar methods for rendering the concrete waterproof, which need not be described here, may be used equally well. (See Chap. VIII, page 426.)

REMOVAL OF EFFLORESCENCE

If the wall be kept continuously wet the water will finally dissolve out all discoloring matter, and will deposit it on the face of the wall. In course of time, rain water beating upon the face of the wall will gradually dissolve and wash off the incrustation, particle by particle, and after a time the whole discoloration will disappear, but this process is slow at best. In fact, the bleaching process may be extremely slow, sometimes lasting for many years before the discoloration finally disappears. The removal of efflorescence may be accomplished by the use of solvents, by wire brushes, by sand blasts, by pneumatic tool dressing, and the like. Each of these methods

involves waiting, it may be a year or more, until the formation of the efflorescence has ceased. Indeed even after years of waiting, there is no assurance that efflorescence will not appear on a wall, and on this account any attempt to remove it by scraping or dressing will prove futile. Efflorescence, however, can be removed by scrubbing the surface with dilute hydrochloric acid as described below; but it may return. The only way to actually prevent efflorescence is to waterproof the concrete as mentioned above. Where the efflorescence extends over the surface of the wall, it may be covered up by the use of cement coatings or waterproofing compounds.

Sylvester Process.—The Sylvester process, consisting of alternate applications of hot soap and alum solutions, has proved effective in the removal of efflorescence. (See page 437.)

Acid Washes.—Washes of diluted hydrochloric, acetic, or oxalic acids may be used to remove efflorescence. Hydrochloric (muriatic) acid is generally used for this purpose, one part of acid to six or ten of water. Very often the acid is diluted with 4 or 5 times its bulk of water. The wash should be well rubbed into the pores of the concrete with a brush and should be rinsed off with clean water as soon as the efflorescence has disappeared. The wash must be applied vigorously with scrubbing brushes and immediately washed off with water from a hose to prevent the penetration of the acid. (See page 402.)

Tooling Surfaces.—The efflorescence may be removed by the use of the sand blast, or tool dressing the surface, either by hand or with a pneumatic hammer; i. e., bush-hammering or crandaling with tools operated by compressed air. But, as already explained, there is no assurance that further efflorescence will not take place, and that such mechanical removal may prove only temporary. However, where the surface of concrete is to be tooled over, if this tooling is not done until the water has leached to the surface the sulphates from the concrete, the tooling will remove permanently all the efflorescence.

Art. 32. Concreting at High Temperatures

In placing concrete in extremely warm weather or in arid sections of this country, where the humidity is much of the time at or near zero, the question of the proper amount of water to be used in both the mixing and curing of concrete becomes very important. The importance of this may be grasped when at times the thermometer in the extreme western part of this country will register above 100° F. for ten months in the year, and that for several months of the year it ranges daily from 105° F. to 110° F., with periods of high temperatures reaching to 120° F. in the shade. This is in the land of almost perpetual sunshine, where dews and rains are nil in so far as they may be regarded as having any beneficial effect upon the setting of concrete.

Boiling Tests of Cement.—Under conditions of extreme heat as mentioned above, all cement tests should be made by using boiling water in the mixture, and all cement thus handled, which meets the requirements given in Art. 4, will probably be satisfactory.

Wetting Aggregate.—If the weather is extremely warm or in the arid sections of the country, the broken stone or gravel, and the sand are liable to become heated to a high temperature. Then, in mixing the materials, the water necessary for the crystallization of the cement is rapidly absorbed by the stone and the sand, or else rapidly evaporated by contact with them. Again, the extreme heat will hasten the setting of the cement. This has been known to occur in the mixer causing concrete to cake and stick to the mixer to such an extent as to interfere with its proper working, producing lumpy and inferior concrete. In order to overcome such difficulties, the stone should be thoroughly wetted with a hose, and the sand and stone should be kept under cover, away from the direct rays of the sun. (See page 164.)

Housing the Mixer Platform or Machine.—The mixing platform or machine should be roofed over when mixing is done at high temperatures.

Consistency of Mixture.—The concrete should be of a slushy or sloppy mixture. Unless this is done, certain cements will, in hot climates, take the initial set before the concrete can be mixed and placed in the forms; it will set within one minute of time. All moderately or semi-dry mixtures have to be tabooed. For methods of mixing concrete, see Art. 15. (See also page 194.)

Keeping Concrete Moist (Curing the Work).—The author is of the opinion that too little attention is given to the proper curing of cement work. This is doubtless due to the fact that the idea is prevalent that concrete continues to harden and increase in strength as it ages, omitting the important proviso that a condition of dampness or moisture must be continually present and permeate the entire concrete mass to render the first statement true. If conditions of sun and atmosphere or other causes withdraw the moisture, and the concrete mass or any part of it becomes thoroughly dried or practically so, the increase in strength of just so much of it is at that time permanently arrested and no further application or condition of moisture, no matter of what duration or amount, is of any avail. This extraction of moisture is rapid in an arid country and a cement finish in the evening is found to be on the point of turning white at 7 a. m. the following morning, and to be crying for water.

Under the above conditions an uncovered piece of work will need to be water-soaked four times daily. The practice in sidewalk construction (see Art. 51) is to cover the work lightly with moist earth as soon after it is laid as possible, and follow by thoroughly sprinkling the same later in the day and giving the walk a good water-soaking and a heavy covering of wet earth the following morning, keeping the earth next to the walk wet for at least a week after laying, subsequent to which time it is allowed to dry out slowly. In this connection see page 491.

In other words, when concreting is carried on during hot weather or at high temperatures, the freshly laid concrete work must be kept moist; otherwise, there is great danger of the concrete drying out before the cement has set. There will be no strength to such

concrete. In other words, the concrete must be sprinkled liberally to make up for the loss of water by evaporation, as concrete cannot gain its full strength without water. (See Art. 29.)

Art. 33. Concreting in Freezing Weather

GENERAL REQUIREMENTS

Engineer's Permission.—In case it becomes necessary to do work in the winter months, no concrete should be mixed nor placed, nor any other operation performed, likely to be interfered with by cold during any of the months of December, January, February and March and thereafter until the frost is out of the ground, unless permission be obtained from the engineer in charge of the work. If, however, the engineer is of the opinion that any operation can be satisfactorily performed during the above months, he may give the contractor a special written permit, defining the work and the conditions under which such work may be done, and such conditions must be faithfully followed. The inspector, of course, will be governed by the engineer's decision in the matter. As a matter of fact, however, satisfactory results can be obtained in all classes of concrete work when proper precautions are observed, and prejudice against concreting in freezing weather is gradually disappearing.

Suspension of Work.—The engineer may, however, prohibit the laying of concrete at any time when, in his judgment, the conditions are unsuitable or the proper precautions are not being taken, whatever the weather may be, in any season. The practice of mixing, placing and protecting concrete in freezing weather in the same manner as in warm, is most certainly to be condemned.

Starting Work after Prolonged Freezing Weather.—After prolonged freezing weather the work should not be taken up again with the warmer weather until the approval of the engineer has been obtained.

PRECAUTIONS TO BE OBSERVED

Special precautions must be taken in placing concrete in cold or freezing weather. Concrete in the cold and damp autumn and winter months sets much more slowly than during the summer. Below a temperature of 50° F. concrete sets slowly, and below 40° F. is very inactive. At 32° F. concrete freezes before setting. The freezing retards the setting of the concrete and often ruins it. Concrete work, however, can be carried on during freezing weather if the following precautions are taken: It is preferable to stop concreting at 20° F., although reinforced concrete buildings have been constructed when the outdoor temperature ranged between 0° and 20° F. In a few exceptional cases the weather was from 5° to 10° below zero.

Concrete Materials.—When it is necessary to make concrete in freezing weather, only Portland cement should be used. Avoid very slow-setting cement for such work. Natural cements should not be

used, as they will not stand freezing. In fact, most natural cements are seriously injured by frost, especially by alternate freezing and thawing.

Avoid using sand and gravel containing loam or clay, of which even 2 per cent will greatly retard the setting of any cement with which it may be mixed. Precautions must be taken to avoid the use of materials containing frost or covered with ice crystals during freezing weather. The inspector should examine all materials carefully, and if they are frosty or frozen he should insist upon the materials being heated. (See page 354.)

Careful Inspection Needed.—Particular care should be used by the inspector to see that the forms are properly braced, that bottoms of beam and column forms are clean before pouring concrete; that the steel is accurately placed, concrete thoroughly mixed, and the workmanship in general the best possible. Special vigilance is required of the inspector during cold weather, as workmen are apt to become careless during cold weather. Workmen have a tendency to shirk their duty, especially when it exposes them to the cold.

Cleaning Forms.—Trouble is likely to be experienced from the tendency of frost to make the concrete adhere to the forms. Boiling water may be used with good results in thawing this out. Snow and ice may also be removed from forms by steam from a hose connected to the steam boiler on the job; in this way any particles of ice are melted and the chill taken off the forms.

Warming Steel Forms.—Concrete should never be placed in steel forms until they are warmed, if the temperature is below 32° F. This is done best with steam, followed by hot water.

Methods of Preventing Injury to Concrete.—The precautions which will assist in preventing injury to concrete during freezing weather are as follows:

(1) Lowering the freezing point of the mixing water, i. e., adding less than 10 per cent of salt. (See page 351.)

(2) Heating the sand, broken stone or gravel, and mixing water. (See page 354.)

(3) Covering the newly-laid concrete with some non-conductive material which will retain the heat, i. e., canvas, straw, etc. (See page 360.)

(4) Enclosing or housing the work under construction. (See page 362.)

(5) Artificial heating of the enclosed space. (See page 363.)

One or more of the above methods should be employed to prevent concrete from freezing. The particular method or methods to be used will depend largely upon the character of the work; large, plain mass work, such as retaining walls and abutments, not requiring the same care and protection as thin walls, columns, beams and floor slabs.

In addition to the precautions stated above, the contractor should be required to take such other precaution as may be found necessary to secure first-class work in every respect, including the character of the finish of all exposed faces.

USE OF CHEMICALS

Lowering the freezing point of the concrete is the simplest and cheapest, but probably not the best method of concreting in freezing weather. This method is only effective for temperatures but little below freezing.

Adding Substances to Mixing Water.—The addition of some chemical to the mixing water is more frequently resorted to than heating the materials as described below, principally, no doubt, because of the simplicity of the process. Only those substances that have no effect on the strength and durability of the concrete should be used to reduce its freezing point. Where such materials as glycerine, alcohol and sugar are proposed for the purpose of lowering the freezing point of water, they should be used with caution, owing to a tendency to lower the strength of the concrete. If any other substance than sodium chloride (common salt) or calcium chloride is proposed for the purpose, the approval of the engineer should be obtained before its use is permitted.

Salt in Mixing Water.—Salt dissolved in the water used in mixing the concrete helps to prevent freezing by lowering the freezing point, and is the ingredient most commonly used, the addition of which lowers the freezing point about 1° F. for each per cent added. When salt is added to prevent freezing, the amount should not exceed ten (10) per cent of the weight of the water. Some authorities place the safe percentage at a considerably higher figure. A 5 per cent solution of common salt is quite often used and is not detrimental to the strength of the concrete where so used. Even a 10 per cent solution of salt will only reduce the freezing point a small amount, so it is of limited value.

The rule for using salt is as follows: Freezing point is 32° F. Concrete requires at least three hours to set, so a guess must be made as to the number of degrees the temperature will fall below freezing before the setting is complete. Subtract this temperature from 32 and the result is the percentage of salt to use. This is the percentage of salt to water by weight as stated above. For example, it is assumed that the temperature will fall to 26° F. before the concrete can set. Subtracting 26 from 32 gives 6 per cent of salt to each 100 lbs. of water used in the concrete. One American gallon of water weighs 8.33 lbs. and one British gallon weighs 10 lbs. Multiply the number of gallons of water by the weight per gallon and get the total weight of the water; then 6 per cent of this will be the weight of salt to use. An approximate rule may be stated as follows: Add one (1) lb. of salt to every eighteen (18) gallons of water when the thermometer is at 32° F., and one (1) additional ounce of salt for every further degree below 32.

Salt is sometimes added in sufficient quantity to "float an egg" or to "float a potato." Such determinations are untrustworthy—it takes about 15 per cent of salt to the weight of the water to "float a potato" and about 11 per cent to "float an egg." The salt addition should be determined by actual weight and not guessed at. No more

than 10 per cent should be permitted under any circumstances, and this amount will not be considered effective for temperature lower than 22° F.

Salt has the effect of slightly reducing the early strength of cement, but does not affect the ultimate strength when used in proper quantities. Salt also delays the setting of cement, but there is no mechanical action from freezing, and the results of its use are usually satisfactory.

The only objection to salt is that it is liable to cause a white, powdery deposit on the surface, which, however, is likely soon to be washed off or blown away. Where the appearance of the surface is an important factor, salt should not be used, as there is danger of efflorescence, which may disfigure the work. Dissolving the salt in the water rather than mixing it with the cement lessens the possibility of efflorescence. (See Art. 31.)

If salt is added to the water, great care should be taken to see that it is thoroughly dissolved and that the solution is not overdosed, which is very likely to be the case. If the effect is not bad on the strength of the concrete, it is on the looks of it. Too much salt, or salt in lumps, will eventually work its way to the surface, thus showing in blisters and unsightly stains. Salt should not be added in lumps directly to the mixing water, but in the form of brine, which may be prepared as follows: Make a barrel of saturated solution of salt, in which a layer of free salt is kept showing in the bottom; put one-tenth of the contents of this barrel, dipped from the bottom, into each barrel of fresh water used for mixing. It is useless to provide easily broken salometers which the foreman will not use, as this simple plan more readily provides a 10 per cent solution, which will retard freezing, as stated above, and which will not injure Portland cement concrete; and which, in some cases, will even increase its strength. Even when salt is used it is important that the aggregates be free from lumps of frozen material, as it is impossible to properly mix such materials. Many New England contractors use two pounds of salt to each bag of cement.

Sometimes salt is used when the materials and water are heated; but since salt retards the hardening of concrete and lowers its initial strength, while the heating of the materials and the mixing water accelerates that hardening and enables the concrete to gain strength more rapidly, it is evident that much better results would be obtained if the salt were eliminated and more attention given to heating the materials and protecting the concrete after it is placed.

Salt should be used only in plain concrete work, as its effect on reinforcing metal has not been established. It is claimed by some experimenters that salt will corrode steel bars embedded in concrete. (See page 353.)

Where there is a possibility of electrolytic action in concrete construction the use of salt is to be discouraged, as concrete containing salt would be more susceptible to such action than concrete free from salt.

Concrete to which salt has been added dries out more slowly and

hence retains its dark color longer than that containing no salt; but both are likely finally to have the same color.

Calcium Chloride in Mixing Water.—Calcium chloride (chloride of lime) is the best material known to prevent concrete from freezing before it sets. Experiments indicate that calcium chloride added in quantities not exceeding two (2) per cent of the weight of the cement is an effective agent for lowering the freezing point of the concrete. It is also a well-known fact that additions of calcium chloride will often render unsound cement sound. Mr. Richard K. Meade added 2 per cent calcium chloride to several samples of unsound cement, and in each case the resulting mixture passed the steam and boiling tests perfectly.*

Calcium chloride may be used in concrete blocks which are made in the winter time, adding to their strength and impermeability, without causing discoloration of, or efflorescence on, the blocks. (See Art. 55, page 520.)

Calcium chloride has an advantage over common salt in that it reduces the freezing to a lower point. Chloride of barium in small quantities has the same effect as chloride of calcium in hastening the setting of cement.

Calcium chloride should not be added in quantities exceeding two (2) per cent of the weight of the cement when used as an agent for lowering the freezing point of the concrete. This is substantially a 15 to 20 per cent solution, the freezing point of which is from 14° to —2° F. In other words, dissolve in the water needed to properly mix the concrete 2 lbs. of calcium chloride for each bag of cement used. To determine the amount of calcium chloride per barrel or tankful of water, the quantity of water used per bag of cement must be carefully noted, and from this the amount can be readily figured. The use of chloride of calcium in concrete should be by special arrangement and under the special supervision of the engineer. If a larger quantity than stated above is used, it is likely so to hasten the set as to make the concrete difficult to handle. As a general rule, 1 lb. per bag of cement seems to be sufficient for most purposes.

Corrosion of Steel Rods in Reinforced Concrete.—Tests were made during 1908-9 by B. Knowles and Clifton P. Mayfield, Philadelphia, to determine the relative effects of various percentages of sodium chloride and calcium chloride on reinforced steel embedded in concrete.†

From a study of the observations and tabulated weights of the reinforcing bars, Messrs. Knowles and Mayfield reached the following conclusions:

(1) The presence of sodium chloride or calcium chloride in the aggregate causes a corrosive action on metal.

(2) This action is greatest on the under side of the bar.

(3) This action is greater in concrete of dry consistency than in one of a wet consistency.

(4) The denser the aggregate is proportioned, the less the action.

* *Engineering Record*, April 20, 1907, page 502.
† *Engineering News*, Feb. 8, 1912, Vol. 67, page 258.

(5) The corrosion increases with an increase of percentage of the salt in the aggregate.

(6) The action caused by calcium chloride is greater than that caused by common salt.

Experiments should be carried further to ascertain whether the action noted above would continue until the effective strength of the steel would be dangerously impaired.

The author would suggest that concrete reinforced with steel should not be protected from freezing by the use of salt, owing to the results of the above experiments. It is a well-established fact that salt and air corrode steel quickly, and concrete placed in the winter is liable to be somewhat porous and get in, and if there be any steel embedded therein, corrosion will follow.

HEATING THE MATERIALS

The best method of concreting in freezing weather is to heat the materials and to protect the work until it has obtained sufficient strength to withstand the action of frost. Either the water, the sand and water, or the sand, broken stone or gravel and water should be heated. The cement is usually not heated. The simple precaution of waking up the cement by the use of warm water in the mix causes it to deport itself more nearly as it does in the summer season. Heating the materials accelerates the rate of hardening and lengthens the time before the mixture becomes cold enough to freeze. At temperatures not greatly below freezing, the combined effects are sufficient to insure the setting of the concrete before it can be damaged by frost. In other words, the effect of the heat is to make the concrete set more quickly, so that it sets thoroughly before it cools down to the freezing point.

The necessity of heating the aggregates is obvious, since when boiling water is thrown into the mixer it has such speed of operation that not enough time elapses to thaw frozen masses and get them properly distributed before the mixing process is complete.

Heavy Mass Work.—For heavy mass work, thick walls, abutments, etc., it is not necessary to heat the broken stone or gravel, except in unusually cold weather; but sand and water should be heated. If the concrete goes into place unchilled it will harden rapidly, as mass work retains its heat for a long time, and additional heat is generated during the process of handling.

Reinforced Concrete Work.—For reinforced concrete work it is necessary to heat all the materials but the cement, and the concrete should be hot when placed in the forms. The reinforcing steel should also be heated to the same degree as the concrete, or a steam hose and jet used to take all frost out of the steel bars before pouring the concrete. Where it is possible to obtain sand and broken stone or gravel that is dry and free from frost, these materials will not be required to be heated, but if not they must be heated. The cement is not heated, as its setting is hastened to too great an extent.

Amount of Heat Required.—There are no test data that show how

long it takes a concrete mixture at a certain temperature to lose its heat and become cold enough to freeze at any specified temperature of the surrounding air, and a theoretical calculation of this period is so beset with difficulties as to be impracticable. The amount of heat required depends upon the temperature of the air and the rapidity with which the work can be done after heating stops.

The water should be warmed, but not boiled, for too much heat will hurt the cement. The sand and other aggregates should be heated, but not enough to blister the skin of the hand. If the concrete should be deposited in mass while warm, it will retain the heat for several hours, giving the cement time to take its initial and final set. In each period there is little danger of injury from freezing.

Some specifications require that all sand, broken stone, gravel and water used in mixing the concrete in freezing weather shall be heated to a temperature of not less than 150° F. and the concrete placed while yet steaming. There is some danger in killing the cement with such boiling hot water. The temperature of the water should not exceed 130° F. at the most, and should preferably be 120° F. Ordinarily the heat cannot be so great as to injure the material itself, but it may kill the cement by hastening its set to such an extent as to cause trouble, or to so dry out the broken stone that it will absorb enough water to rob the cement of necessary moisture in dry mixtures. In other words, the broken stone must not be overheated, but must be moist enough not to dry out the mortar when mixed with it. In heating the materials, too high a temperature will cause sand to turn red, while stone and gravel are apt to soften or crack. The sand should be warmed the same amount as the broken stone or gravel.

Use of Boiling Water.—As stated above, the concreting may be carried on in freezing weather by using boiling water for mixing (tests should, however, be made to determine whether the hot water does not injure that particular brand of cement in regard to strength), and by pouring boiling water on the forms, and especially the reinforcement, so that not a particle of ice or snow remains. No concreting in cool weather should be commenced unless all preparations for boiling water are made. It is a mistaken notion that hot water freezes more quickly than cold water. When considered necessary, in addition to using hot water, a pint of salt per bag of cement may be added to the mixture. The use of hot water cannot always be depended upon to thaw out frozen, lumpy sand or stone when mixing concrete. All hard lumps should be thrown out before they reach the mixer.

Methods to Be Adopted for Heating Materials.—The materials can be heated in various ways. The method to be adopted for heating the materials will depend largely upon the character of the work and the arrangement of the mixing plant. Elaborate and expensive plants for heating materials have been constructed and successfully used on important work. However, extremely crude methods may be used successfully where the importance of the work doesn't warrant any considerable outlay for apparatus.

Ordinary Heating of Aggregates.—A small stove built roughly of sheet iron will serve for a very small job of concreting. Two lengths of stovepipe, laid flat, with a fire built so that the gases go through the sand and gravel placed in a pile over the pipe, is often sufficient when mixing is done by hand for a small job.

For larger jobs, lengths of old steel or metal culvert pipes closed at one end and provided with a short piece of smaller pipe for a flue may be used, covering them with the sand and stone. Fires are built at one end and pushed through as new material is added. Sometimes, long half-cylinders of sheet steel set directly on the ground in the form of an arch are used, coarse screens being placed over them. A stovepipe in the farther end will insure a draught. The sand and stone are shoveled over the screens, and lumps thus broken, the materials falling down to the hot half-cylinders and keeping warm until used. Sand and broken stone or gravel may also be heated by means of an ordinary sand heater such as is used for heating gravel used in street paving work.

For weather not too severe and the amount of aggregate to be used not too large, say, 50 cu. yds. per day, the materials may be heated by building wood fires near the supply piles; that is, both sand and broken stone or gravel. If a fire be kept burning over night on top of the piles of sand and stone, a considerable quantity can be heated. The fire can be kept going during the day and moved back on the pile as the heated material is used. This method of heating aggregates requires a quantity of fuel which in most cases is prohibitive and is not sufficient to supply a power mixer.

Steam Coils.—Aggregates may be heated by means of a steam coil placed near the cars that are being unloaded, by simply throwing the material on the steam coil and allowing the sand and broken stone or gravel to remain a sufficient length of time to absorb the necessary amount of heat. The best results would be obtained if the pipes were drilled with small holes every two or three feet, so that small jets of steam would be circulated through the materials.

In many cases material which has already been unloaded must be heated. The expense of putting steam pipes under it is considerable. To avoid this, one or more steam jets may be used, the end of the jet pipe being pushed several feet into the pile of material. In addition, the material may be covered with tarpaulins. If the jets are connected up with steam hose they are easily moved from place to place. With a good steam pressure this system is quite effective. It will be found difficult, however, to heat stone by means of a steam jet placed in the manner just described, except in moderate weather, owing to the fact that broken stone requires much more heat than sand or sand and gravel mixed, because of the greater volume of air spaces. If the material so steamed is not used at once it will give more water, therefore more ice to contend with in the material pile.

The use of steam, however, has this advantage over the use of sand heaters described above, in that where the latter are used there is danger that the hot fire necessary to thaw out the material at the top of the pile will damage some of the material next to the heater.

Steam Boxes.—A very convenient method of heating large quantities of aggregate is to build a long wooden box, say, 8 to 10 in. square, with numerous holes bored in its sides. This box is then placed on the ground, connected with a steam pipe, and covered with sand, broken stone or gravel. The steam thus escaping through the holes in box will generally heat over night, a pile of sand or sand and gravel mixed, 8 or 10 ft. high. Perforated pipes as mentioned above can be substituted for boxes, though usually more expensive. Material can always be heated more rapidly if the steam be allowed to escape in the pile than if it is confined in pipes which are not perforated.

Salamanders.—Another method of heating the sand, broken stone and gravel is by means of a large salamander. This may be accomplished by providing a double hopper bottom of sheet metal to a supply hopper of sufficient capacity to store at least a day's run. The heat from the salamander is thus led into the air space directly under the aggregates, and the necessary draft is supplied by chimneys passing through the aggregates. This method will generally be found very effective in extremely cold weather. It will frequently be found more economical to build heaters of brick laid up dry, with large end joints, than to buy salamanders.

Heating the Water.—For heating water, the common practice of relying upon a steam pipe placed in an ordinary barrel should not be permitted, as the water is generally used too fast to permit of its being properly heated by this method. A suitable tank should be provided and the water heated by means of a coil supplied with steam from the boiler supplying the mixer engine, or when this is inadequate one should be erected for this purpose. The size of the tank will be governed by the time required for heating it. Close inspection will be necessary to insure that the water is not used more rapidly than it is heated.

The most practical water heater for concrete mixed by hand and in small quantities is an iron kettle with a roughly built up brick or concrete block setting. The water may be heated by setting two barrels a few feet apart and connecting them by a straight pipe near the top. Near the bottom another connecting pipe is formed into a coil, under which a fire is built. Both barrels are filled with water, and a circulation soon begins when the fire is built, so that all the water is warmed. Water for mixing concrete may also be heated by passing through pipes coiled in a salamander.

MIXING AND PLACING OF CONCRETE

The practice of mixing and placing concrete in freezing weather in the same manner as in warm is to be condemned. It is absolutely imperative to mix and place concrete in such a manner as to insure proper hardening during the first few days. Freezing will not damage concrete that has had a chance to harden under favorable conditions, but alternate freezing and thawing is very apt to damage green concrete.

Frozen Aggregates.—Care must be taken to screen out all frozen lumps from the sand and stone and remove all ice and snow crystals. The use of frozen, lumpy sand or stone, depending on hot water used in mixing to thaw it out, should not be permitted. The use of hot mixing water cannot be depended upon always to thaw such lumps, and they may form a considerable pocket of uncemented material in the finished work. In a small column this might be disastrous. All hard lumps must be thrown out.

Housing and Heating the Mixer.—The mixer should be enclosed in a frame housing, covered with tar paper. The mixer should also be kept warm by means of steam coils outside and jets inside. The exhaust steam from the mixer engine may be turned into the drum of the mixer. This is accomplished by conducting the exhaust pipe to a point in front of the discharging opening of the drum, so that the drum when tilted for discharging will just clear the end of the pipe. The force of the exhaust will then carry the steam into the revolving drum, where complete mixture with the dropping particles of concrete utilizes practically all the heat remaining in the steam. Canvas flaps should be hung over the feed and discharge holes in the mixing drum so that escaping steam will not interfere with the workmen.

Mixing Concrete.—Use a little more cement than in warm weather. If the aggregate is porous it should be well soaked in water before coming in contact with the cement; otherwise it will absorb the water necessary for mixing and for developing the full activity and strength of the cement. Boiling hot water should never be brought in direct contact with the cement, but first mingled with the aggregate, which will sufficiently distribute the heat and lower the average temperature to a safe working degree.

In general, less water should be used for mixing in cold than in warm weather, as the less water used, the quicker will be the setting and maturing. Since the injury due to frost is caused by the expansion of the water used in gauging, concrete mixed wet will suffer most. Concrete, therefore, should not be mixed too wet for use in low temperatures. On the other hand, do not use what is known as the "dry mix" in freezing weather. The concrete must be pasty and sticky, so it will not run freely from the wheelbarrows or carts. (See Art. 15.)

Do not use salt water for mixing concrete if it is desired to show no efflorescence. (See page 342.)

Handling Concrete.—Placing of concrete in freezing weather should be carried on continuously to insure a perfect monolithic mass. The greatest care must be exercised in using reinforced concrete during winter months. The concrete should be placed in the work at a temperature of at least 60° F., regardless of the temperature of the surrounding atmosphere. See that each batch of concrete is placed in the work immediately after mixing. Warm concrete sets up so quickly that occasionally when there is a tie-up for a few minutes in the wheelbarrow line it is not uncommon to find the concrete partly set when a man tries to dump a wheelbarrow load.

If the concrete obtains its initial set inside of 30 minutes, add a little cold water while mixing, to reduce the temperature.

On the other hand, it may be found necessary to take additional precautions to make certain that the concrete will go into the work unchilled, instead of being too warm. One contractor, who was obliged to convey the concrete a considerable distance from the mixer to place, used a novel method of preventing the concrete from becoming chilled on the way. A cupful of gasoline was poured into each empty concrete car on its return to the mixer and lighted. The sudden heat generated was sufficient to heat the metal car so that the fresh batch of concrete was not chilled.

The chuting of concrete in winter should not be permitted. (See Art. 35, page 369.)

Minimum Temperature for Concreting.—In freezing weather, concreting should be stopped at the temperature required by the specifications or as may be required by the engineer. In general, no concrete should be made or placed when the weather is, or is predicted to be by the United States Weather Bureau within 12 hours, as low as 20° F. The author is well aware of the fact that concreting is carried on when the weather is below zero, but he does not recommend such practice. The inspector should obtain reports from the Weather Bureau to find out whether or not a cold wave is expected. If such a drop in temperature is expected, it is better to suspend work than run the chances of a severe drop in the temperature just after the concrete has been deposited. The forecast of the Weather Bureau will generally be found of great assistance in determining whether or not it would be advisable to concrete. The minimum temperatures predicted by the Weather Bureau are very accurate indeed.

Concreting Thin Walls.—On thin walls, the time of concreting should be limited to 28° F. on a rising thermometer, and 32° F. on a falling thermometer.

Facing Concrete Work.—No concrete work that is to have a face finish should be placed in freezing weather, unless absolutely unavoidable, as frost is very apt to affect the surface, causing exfoliation, spalling, pitting and discoloration.

Diminishing Area of Concreting.—In the winter time the area of concrete work should be cut down by the use of bulkheads, so as to decrease the time of exposure of a single layer, which will result in running the work up to a greater height for a day's work.

Accumulation of Surplus Water on Concrete.—In no case should a surplus of water be allowed to accumulate and freeze on top of a layer of concrete and then be covered up with more concrete before thawing out. If too much water is used in the concrete the expansion of the water in freezing may disintegrate the concrete by the mechanical action of the ice in forming, causing a crumbling of its outer surfaces.

Bonding New to Old Concrete.—Where the new concrete joins the old the edges should be thoroughly steamed. (See Art. 27.)

Removal of Defective Work.—Whenever any cement work freezes

before it has become thoroughly set, the entire mass should be removed, since the bond of the concrete which has been frozen will not be as hard to the unfrozen layers as if it had not been frozen. A slight frost extending only ¼ in. into the concrete is not detrimental to strength. It is even claimed that concrete can be frozen, thawed out, and will then reset. This may be so in some cases, but it is always best to remove any concrete in which the freezing has extended throughout the mass. The freezing of a layer of concrete is apt to prevent a good bond with another placed on top. Layers of concrete which have frozen should invariably be removed before laying fresh concrete upon them. No sudden removal of frost and ice on the surface by using hot water or steam should be permitted, but should be removed by the use of cold water. The use of fires for the removal of frozen concrete surfaces should be prohibited.

Suspension of Work.—The engineer may, when he deems it best, stop all concreting when the weather is at or below the freezing point. Care should be taken that each day's work is finished off to a horizontal or level line, so that the work may, if necessary, be left in the proper shape for an indefinite period.

PROTECTION OF CONCRETE

When once hard, no hydraulic material is less affected by extreme cold than Portland cement concrete, but in the early process of set and hardening it should be protected from freezing, though some cases are cited* where solid freezing in this stage showed no damaging results. It may be true that concrete is not injured by freezing, but the setting is delayed and the thawing causes expansion, so that injury may be done before the concrete can set. It is not advisable to depend upon frozen concrete resetting. The safest plan is to avoid freezing, especially in surface work. Frozen concrete is especially dangerous in the construction of reinforced concrete buildings, because it very often possesses the apparent solidity and hardness of concrete that has properly set, and its defectiveness is only apparent on the removal of the forms and the subsequent thawing out of the concrete. (See also Art. 29, page 333.)

Covering Concrete.—Any concrete liable to be exposed to sleet, frost or snow before it has attained its permanent set should be protected from the cold so that it will not freeze. Concrete in setting develops considerable heat and it is only necessary to prevent this heat from leaving too rapidly in order that the cement can set before the freezing point is reached. Even if the concrete materials are heated (as described above), the heated concrete should invariably be protected by suitable covering to insure the concrete setting before it has cooled to a freezing temperature. It frequently happens that the concrete will be mixed and placed during the daytime, when the temperature is 32° F. and then left to set during the night, when the temperature will drop from 5 to 15 degrees. Concrete that is exposed to such conditions must always be covered before stopping work at night, even though it is warm during the daytime, as the

* *Engineering News*, Feb. 6, 1896, page 92.

nights are very often below freezing temperature. A covering of sufficient thickness should be used. No concreting in cool weather should be permitted unless suitable coverings in ample quantities are at the site.

Concrete laid in cold weather in large masses and below the ground can be protected from freezing by permitting water to rise up over night and then pump it out the following morning. The laitance and silt which accumulate under such procedure, of course, should be carefully cleaned off.

There are innumerable coverings for the top surface of concrete to prevent freezing. Boards, canvas, tar paper, sacking, cement bags, sawdust, shavings, manure, straw and sand are all used for the purpose.

Use of Boards and Canvas.—Protection of setting concrete may be afforded by a layer of boards, leaving an air space of several inches, and laying canvas over the boards. An air space beneath the canvas is valuable. The edges of the canvas should be brought down to enclose the air space. Two layers of canvas, separated by boards, will give very material protection. If only a single layer is used it should not be allowed to touch the concrete but should be kept out by boards. Do not depend solely on canvas spread directly on the surface as a covering to protect concrete from freezing. Hay, shavings, or some other material in which quiet air may be entrained, should preferably be placed on top of the canvas, whether boards are used or not.

Use of Tar Paper.—Tar paper should be well lapped and used as suggested for canvas. In temperatures only a few degrees below freezing it is sufficient to nail building paper on the outside of the forms. A single thickness of tarred paper, well tacked and so put on as to prevent a free circulation of air, has raised the temperature of the air under it 15° F.

Use of Cement Bags.—Cement bags used for protection should be in layers and well lapped. If this is not done, the concrete will be frozen between consecutive bags. At two or three spots where the bags had not been properly lapped, on a certain job, the concrete was frozen to a depth of 1 in. The balance of the concrete was not affected by frost, three layers of cement bags being used to protect the top surface of the concrete.

Use of Sawdust.—Sawdust, when available, will probably supply the best protection, with little danger of injuring the concrete. The author knows of no better material for covering freshly deposited concrete in cold weather. Manure comes next, and in some respects it is better than sawdust.

Use of Manure.—The use of manure should not be allowed for the covering of concrete, as it causes disintegration, unless the concrete is well and sufficiently covered so as to be waterproof against the drainage therefrom. Manure must be used with care for protecting concrete in cold weather. If stable manure can be kept in place in sufficient quantities to keep its fermentation it is the most

efficient material for covering, as it is a heat generator; but it discolors the concrete (this is seldom of import). (See page 491.)

In no case should fresh manure be placed over very green concrete to protect it from freezing, as it will spoil the surface of the concrete. When possible, the concrete should first be covered with boards or tar paper and the manure placed upon them. This will keep the manure from soiling the concrete and prevent any action of gases generated by the decaying materials. Considerable care should be taken, however, to protect the manure from becoming wet during rain storms. If possible, it should be covered with tarpaulins, or with planks arranged in such a manner as to exclude the water. This is a practical and yet a very inexpensive way to protect concrete in the open where a low, flat surface is presented. A thickness of 12 in. of manure laid on tar paper or canvas and kept dry will protect the work from freezing for days at a temperature as low as 10° F.

When stable bedding or manure is used, the concrete may be covered with an inch of sand before the bedding or manure is spread. This sand will then prevent the bedding or manure from coming in contact with the cement, and the sand will absorb the acids in the manure before they reach the cement.

It is probable that only green concrete is injured by manure, as it has been used widely for stable floors, manure bins, etc., without any evidence of failure.

Use of Straw or Hay.—A covering of straw or hay may be allowed on certain conditions. Straw should be used at least 12 in. deep, and, in extreme weather, deeper. In conjunction with the tar paper and canvas, it works very well.

Protection of Concrete by Artificial Heat.—Concrete may be protected from freezing by the use of artificial heat. This may be accomplished by inclosing the entire work under cover and keeping it warm by heating the air within the enclosure. This is rather an expensive method and is seldom employed except in building construction. The inclosing framework is lightly constructed of wood, covered with canvas or other material.

Forms may also be so constructed as to protect all parts of the concrete from injury by frost, radiators or live steam being used within the forms sufficient to keep the temperature above 35° F. during, and for at least two days after, the placing of concrete.

In reinforced concrete construction during winter it is generally necessary to provide some heating system to prevent the work from freezing. Steam pipes, stoves or open charcoal fires may be used for this purpose. Any method for heating concrete work that does not provide moisture as well as heat should not be considered. It is absolutely essential that concrete be not forced to take its set quickly.

Use of Steam Pipes.—Concrete may be protected by covering with canvas and running a jet of steam under it. If canvas is not available, boards and straw, or manure, will answer for the purpose. The inspector must see that these pipe lines are well covered with some non-conductive material which will retain the heat. If heat is kept

on for 36 hours after completion, this is sufficient, except in unusually cold weather. If the forms are tight and made of heavy material it will only be necessary to protect the top or exposed surface of the work with canvas and apply a jet of steam to the boxed area.

Reinforced Concrete Buildings.—In building construction the reinforced concrete must be kept from freezing and maintained at a fairly high temperature to permit proper hardening. This will necessitate enclosing the building in temporary walls of canvas or boards and roofing it over. The interior should in all cases be kept heated by using stoves, open charcoal fires, etc., so that the enclosed space does not vary in temperature more than a few degrees. Keep the building at a uniform temperature of about 60° F. This heating should be continued for several days, and the concrete should then be examined. If found to be in good condition, properly set, and with no evidence of having been frosted, the stoves or salamanders may be removed, but the covering should be left in place for at least another week.

Care must be taken to see that the concrete and the forms are not allowed to dry out when salamanders or other artificial heaters are used to keep the work warm. There is a danger of the concrete baking in the forms, which necessitates constant watching. A moist temperature is absolutely essential, and to obtain this, either steam or water must be applied to the centering to avoid a dry heat and too rapid setting of the concrete. In other words, moisture is very essential to the proper setting of concrete (see Art. 29), and the loss due to evaporation from concrete and forms by dry heat must be replaced by sprinkling or other means. Where steam is not available, the under side of the floor forms should be sprinkled with cold water until they do not feel warm to the hand.

The protection of floor slabs must be carefully observed. In addition to placing salamanders or other artificial heaters under the floor being concreted, the slabs should be covered with a layer of about 12 in. of straw or hay. In very severe weather, the author would suggest that a number of air-holes be provided through the slab and an air space left over the slab to give the heated air a chance to pass above the floor and distribute itself over the entire top surface. The floor should be covered with a layer of boards, leaving an air space of at least 4 in.; over the boards lay tar paper or canvas, and bring the edges down to enclose the air space. On top of this covering use hay or straw or manure. Straw is sometimes sprinkled with salt.

A system of heating by means of live steam jets has been found to be very satisfactory in reinforced concrete building construction, and no bad effects were experienced from frost. Steam pipes can be run above each floor and under the layer of boards and tar paper or canvas, from a boiler employed for the purpose. The same boiler may be used to heat the sand, stone and water (see page 357), and the exhaust steam may be discharged into the rooms and under the floor covering to heat them and keep the air moist. This will assist in quickly hardening the concrete during cold weather. (See page 362.)

Surface Finish for Important Structures.—For a spaded or mortar finish (see Art. 41), extreme care must be taken to protect the work, preferably by covering the outside of the forms with a layer of tar paper so as to leave an air space between it and the face lagging. Tests have shown a difference in temperature of 15° F. between the air in the air space and the outside atmosphere. Care should be taken to tack this paper on securely. Structures in which the surface finish is important must not be permitted to freeze until the concrete is well set. Mortar facing which is once frozen is usually permanently injured, due no doubt to the expansion which takes place during freezing. Blocks of the lagging, say, 4x12 in., at different points of the most exposed sides of the work, may be cut out, in order to note whether or not the mortar facing is being affected by frost. If the concrete has been frost-pitted, on the surface only, bush hammering will give a rough stone finish, pleasing in appearance. (See page 403.)

Protection of North and West Sides of Structure.—Special pains should be taken to protect the north and west sides of the structure. Canvas curtains may be hung on the north and west sides of the building to keep out the wind. The side from which the wind blows is more liable to be frozen than the sides that are protected from the wind.

Protection against Heavy Loads.—Work to be placed upon concrete laid in freezing weather should be delayed until the setting of the cement makes the mass sufficiently stable to carry the weight, as heavy pressure tends to retard the setting. Usually as much as 48 hours or more should be required before masonry or other heavy weights are laid upon the concrete. Careful inspection of winter concrete should be made before loads are applied. In massive walls the rise of temperature due to chemical action in setting will be sufficient to enable the concrete in the interior to set before freezing, so that such walls will acquire considerable strength during cold weather. Thin walls, if allowed to freeze, will gain very little strength during continued cold, and must be loaded with caution.

Duration of Protection.—All reinforced concrete should be kept at a temperature above freezing for at least 48 hours after being put in place. Concrete, if properly cured, should be immune from damage by frost within 48 hours.

REMOVAL OF FORMS

The most important precaution, and one the importance of which cannot be overestimated, is *caution in the removal of the form work.* Great caution must be used in cold weather, as the concrete sets slowly. Sometimes, two weeks or more after placing, it is possible to drive a nail into the concrete, which indicates how seriously the setting of cement is delayed. (See Art. 19.)

Careful Inspection Needed.—Careful inspection of winter work should be made before removing the forms, owing to the close resemblance between frozen and thoroughly hardened concrete in

appearance. Frozen concrete as a rule cannot be detected by ordinary inspection from concrete cured under natural conditions. It frequently shows a fracture through the aggregate and will ring when struck with a hammer.

Removal of Forms.—All forms under concrete placed in freezing weather should remain until the season has advanced beyond the probability of a frost. If earlier removal of forms is permitted, they should remain until all evidences of frost are absent from the concrete and the natural hardening of the concrete has proceeded to the point of safety. Forms for such work should be kept in place at least two weeks longer than customary. Special care must be used in removing centering when the concreting has been done in cold weather.

Falsework must never be removed while the concrete is frozen. If necessary, artificial heat must be employed to thaw the whole mass and the set and hardness determined before removing falsework. In other words, don't remove any forms until absolutely certain that the concrete is thoroughly hardened and that no portion is either soft or frozen. One way of knowing when the cement is fully set and the concrete properly hardened, is to actually test it with a hammer for hardness. To do this it is necessary to remove small portions of the form work in each section of the structure, to be certain that there are no soft spots. A better method is to cut out a chunk, place it on a hot stove, and see whether it sweats and softens up. If it crumbles it means that the concrete has become frozen and forms cannot be removed until it has warmed up and set permanently. A single freezing will not necessarily injure the work, provided forms are left on and it has a chance later to harden thoroughly.

POINTING AND REPAIRING SURFACES

Finishing.—Pointing up or finishing outside surfaces during cold weather should never be attempted. Even when the weather during the day is favorable it is objectionable to do pointing, as the frost at night will do injury to any work attempted. In all cases this work should be left until the temperature is high enough to insure the work will have time to set hard before freezing.

Repairing Frozen Surfaces.—The remedy after the concrete surface is frozen where the material lost has not got to be replaced, is to re-surface that material which is left. If it must be replaced, the texture of the surface originally desired must determine largely the method of treatment. If this be a plastered surface (see page 410) it is a simple matter to roughen up the back to give a key for plaster and to place it on. If it is to be a tooled concrete surface (see page 403), then a sufficient mass must be removed to enable a new facing to be placed, including aggregate of the same size and proportions as in the original work, in order to build out the face and also to have sufficient strength and stability either to stand by itself or to be properly keyed by suitable methods like the use of reinforcement, to the back.

Concrete surfaces damaged by the action of frost may occasionally be repaired by moistening the surface thoroughly and then applying to it, in a sort of rough-cast, a mortar of 1 part of Portland cement and 2 parts of sand. In this connection, see Art. 30, page 337.

Art. 34. Rubble Concrete

In the construction of massive work, such as walls, piers, abutments, dams, breakwaters and the like, the embedding of stones of "one-man size," or larger, in the concrete, is a practice that has long been in vogue. The embedded stones decrease the cost of construction, since the cost of crushing the embedded stones is saved, and also since no cement is required to combine these stones into a solid mass. In fact, a considerable reduction in most may be obtained by the introduction of large stones without sacrificing in any way the strength or fitness of the structure. The objection is sometimes made that the incorporation of large stones into concrete interferes with the homogeneity of the wall and that variations in expansion may result in injury to the work. This danger, however, is more theoretical than real, especially in large, massive work. This form of construction, however, is suitable only for massive work where the walls are not less than 3 or 4 feet thick.

Designation of Rubble Stone and Rubble Concrete.—These large, irregular pieces of stone are called *rubble,* and the concrete made by using them is known as *rubble concrete.* Stones used in the manner mentioned above are also sometimes called "bulk-swellers," "plumbs," "one-man stones," "niggerheads," "boulders," "packing," "displacement stones," "pudding stones," or "cobblestones." Where the stones are placed so as to show on the face of the work, or where the rubble stones are very large, it is now customary to use the term "cyclopean masonry" instead of rubble concrete to describe the work.

Careful Inspection Needed.—The inspection must be thorough in order to insure water-tight work by a thorough compacting of the rubble concrete. It cannot be too strongly emphasized that the difficulties of inspection are much increased when rubble concrete is specified, as there can be little check on the quantity of large stones which a contractor can put into a wall. For this reason it is sometimes better, in contract work, where the constant supervision of an inspector is not available, to forbid at all the incorporation into the concrete of large stones, and to use a well-broken aggregate, irregular in shape and size and containing, therefore, as small a quantity of voids as possible. In this way the cement will bind a larger quantity of aggregate, and the cost entailed by forbidding the use of large stones will be to some extent reduced.

Shape of Rubble Stones.—Rubble stones should be of irregular or well-rounded shape, rather than cubical or square-faced. Square edges act like wedges, tending to cleave the mass when it shrinks in hardening. Rounded stones, on the other hand, embed themselves

more naturally, while irregular shapes tend to key and prevent cracking. Flat stones are less desirable than cubical ones, as their tendency to produce splitting is still more pronounced.

Size of Rubble Stones.—Stones used for rubble concrete vary in size from one to several cubic feet, according to the magnitude of the structure. In heavy engineering works, some of the stones thus inserted contain a cubic yard or more, but in buildings smaller pieces must be used, according to the thickness of the wall or foundation. In other words, the size of stone is limited only by ability to transport and the width of wall.

Proportioning Rubble for Concrete.—The quantity of rubble used will depend on the size and shape of the stone and the method and care with which they are placed. The percentage in different pieces of work of this character may vary from 15 to 60 per cent or more of the whole mass. A greater percentage of a given volume will be filled if the stone is large size than if it is small size. If the rubble is of such size that it can be handled regularly by one man or two men, about 20 to 25 per cent of the space filled by the concrete will consist of the stone, leaving 80 to 75 per cent to be filled with mixed concrete. In the case of stones that can be handled only by a derrick, the percentage may run from about 33 per cent for the smaller sizes to from 55 to 65 per cent for large-size stones averaging 1 to 2 cu. yds. each or larger, the amount of mixed concrete necessary thus ranging from 66 to 35 per cent or less, according as the stone is increased in size. In other words, the percentage of rubble stones employed varies from a few per cent to over half the volume. Most specifications, however, state that large stones shall not exceed 25 per cent in volume of the masonry containing them.

The proportion or percentage of large stone embedded in rubble concrete may be obtained by subtracting from the total volume of a certain concrete the quantity of concrete sent out from the mixer as shown by the number of batches counted by the inspector at the mixer.

Forms for Rubble Concrete.—Forms may be used as in ordinary concrete work (see Chapter IV, page 197), but at times the rubble concrete is laid as a backing to facing masonry, in which case the facing masonry is laid first and retains the rubble concrete until set.

Laying Rubble Concrete.—The stones should be perfectly clean, hard and sound. No rotten or soft stones or rock should be used, nor those which are partly rotten or soft. Rubble stones are better if their surfaces are irregular than if they are smooth or rounded, as the voids of the irregular stone afford better holding power for the cement. The stones must be thoroughly scrubbed clean before being placed in the work, and should be moistened with water immediately before setting in position. The quality of the stone should be equal to hard trap, granite, gneiss or hard limestone.

The stones should be laid far enough apart to be fully encased in the concrete. That is to say, each stone should be so placed that there will be ample room between it and its neighbor, usually from

6 to 18 in. apart. The stones must not lie nearer one another than 4 in., nor should they lie nearer than 6 in. (preferably 12 in.) to the face or beneath the surface of the wall.

The concrete should be wet enough to flow easily around the stones, and should be deposited in layers the thickness of which varies with the size of the stone to be embedded. A very wet mixture is generally used in placing rubble concrete, and in this case the stones may be placed much closer together than when a medium or dry mixture is used. When the rubble stones are irregular in shape, a sloppy concrete must be used to get them thoroughly embedded. If the concrete is not mushy enough to flow into and fill all the spaces, it must be thoroughly tamped to insure that none of the crevices are left empty. Stones that have flat beds, like many sandstones and limestones, can be laid upon layers of dry concrete and have the vertical interstices filled with dry concrete by tamping. The author prefers to have the concrete mixed rather wet and to contain a proportionate excess of mortar in order that the stones may be properly united with the rest of the mass.

The stones should be settled into the concrete already laid far enough to insure their having a full bed of mortar or concrete. If the large stones do not sink into the concrete by their own weight they should be driven in with a rammer, or they should be dropped into place and settled by joggling with bars to drive out the air and bring the stone to a firm bearing. Care must be observed in bedding stones so as to avoid the formation of cavities, and the concrete should completely fill the space between them. See that the stones are well joggled or worked to a good bed with crowbars, and that vertical spaces are prodded and puddled to prevent arching and voids. If this be not done the stone is apt to rock on its bed, to be displaced by ramming the concrete, and to have voids underneath it. The stone may be placed by hand or with a derrick.

In cases where large stones are placed in layers of concrete which are likely to set before subsequent layers are placed thereon, they should be laid with one-half their surface exposed. If a dry concrete is used, the concrete should be thoroughly tamped around each large stone. Thorough tamping about the stone is necessary to insure the cement adhering to its surface, and also to insure a perfect filling of the voids.

In joining new masonry to masonry that has already set, precautions should be taken to secure a perfect bonding by cleaning and washing the work already in place, and by spreading over its surface a thin wash of mortar before the new masonry is placed. (See Art. 27, page 326.)

All edges should be struck off horizontal on any temporary suspension of work.

In placing the large stones, care should be taken to secure as good bonding, both horizontal and vertical, as may be practicable with this class of masonry. Care should be exercised to avoid in any way disturbing stones after they have been set, unless for special reasons particular stones may be ordered removed. Wherever the

bond is broken after a stone has been set, the stone should be immediately taken up and reset.

Art. 35. Depositing Concrete through Chutes

Concrete may be deposited in place by gravity through movable pipes, troughs or chutes provided with elevator, hoists, etc., as may be required. They are also provided with portable frames so that they can be easily moved from place to place as the work demands.

In placing concrete by the gravity system there are three operations: The mixing of the ingredients, stone, sand and cement, in a suitable batch mixer; hoisting of the mixed concrete by skip to an elevated hopper; and the transferring of the concrete through pipes or troughs leading from this hopper to the point where it is desired to be poured.

GENERAL REQUIREMENTS

Segregation.—Segregation (separating the stone from the finer material) must be avoided in depositing concrete through chutes. On account of the velocity which the larger stones attain in passing down the chute, they generally fall some distance in front of its mouth, whereas the mortar, sliding gently down, drops vertically from the mouth, thus counteracting to a great extent the labor bestowed in carefully mixing the ingredients. This will necessitate remixing the concrete immediately after it reaches the bottom of the chute; but no time must be lost either in the original mixing or in the depositing, if this second mixing is to do any good.

Consistency of Mixture.—In chuting concrete, a mixture should be used which is just as wet as it can be and at the same time hold together. A rich mixture will flow better than a lean mixture, and a mixture which has been thoroughly worked in the mixer flows better than one which has not. The inspector should determine the wetness of mixture to be employed by making a few trials with mixtures of different consistencies.

INSTRUCTIONS FOR OPERATING A SPOUTING SYSTEM

The following general instructions for operating a spouting system may be of value:

1. Run about 10 ft. of water in skip.
2. Charge mixers, using mostly sand with the cement and plenty of water.
3. Run up skip with water and drop at once, following up as quickly as possible with a charge of concrete.
4. Run the mixture so that it may have the consistency of a thick gravy, so that when it levels off the rock is seen held in suspension. If when dumped in skip it stands up, it is too thick; if it levels off and shows about an inch of water, it is too thin.
5. There should be a man in the tower to operate the concrete gate on the hopper to regulate the flow of concrete through the pipes

or troughs. The stream should fill about one-third of the conveyor pipe or trough and the charge should be so timed that the stream will be as continuous as possible.

6. The continuous and successful running depends on the uniform mixture. Be careful not to get it too thin. After a shut-down of over 10 minutes, flush the pipe or trough by sending up 10 feet of water in the skip.

7. At the end of the day's run clean out the mixers with two charges of water. Send these through the pipes or troughs.

8. All pipe joints should be oiled with thick grease so as to prevent sticking.

Cleaning Chutes.—Cleaning of chutes is essential at the end of the day's work, and in beginning work again the chute should be drenched with water to lubricate it so as to avoid trouble in handling the first few batches of concrete.

CONSTRUCTION OF CHUTES

With the actual construction of chutes the inspector has little to do, his duties being restricted to seeing that the quality of the work is maintained rather than the means used by the contractor to carry on the work. However, as the inspector is interested in the progress of the work to see that it is completed in the time agreed upon, the method of handling the material may become of vital importance. The author will therefore discuss the construction of chutes very briefly.

Sagging.—Chutes must have ample strength against bending or sagging between supports. If the supports are far apart, the chute should be stiffened by truss rods or some similar means.

Slope of Chutes.—A slope of 1 to 8 is about as flat as concrete will flow without help, even when the travel is short. The inside of chutes, particularly if the slope is flat, must be as smooth as practicable. A wet concrete will flow quite readily on a slope of 1 to 4.

Elbow Connections.—If the chute changes direction, say, from a 45-degree slope to a vertical drop into the forms, the elbow connection should be firmly anchored against shock of the flowing mass due to its change of direction.

Canvas Sleeve.—If the chute has a long, steep, straight run, some arrangement should be made to prevent scattering when the stream discharges. A canvas sleeve extending from the chute, or a short vertical elbow, will ordinarily accomplish the result.

Steel Lining.—The wear from fast moving batches of concrete is considerable, and where a chute will have long use provision should be made for wear. A removal steel lining may be used to take the wear.

Platforms.—Chutes should be built on substantial platforms, high enough in the air to give proper fall to remotest chutes.

Prevention of Separation of Aggregates.—It is necessary that some precaution be taken to avoid separation of the aggregate. This may be accomplished in several ways, either by chains loosely

stretched at intervals across the chute, or by shelves extending part way across the chute at an incline and alternately on opposite sides, so as to give the concrete a zigzag travel down the chute. Either of these methods is a direct benefit, as it more thoroughly mixes the concrete. No chuting should be done in freezing weather.

Art 36. Depositing Concrete under Water

Concrete may be deposited in still water, and will harden there almost as soon as in the air. It should not, however, be placed under water, unless unavoidable. Only relatively massive work should be concreted under water, and where great strength is not required. Porous and imperfect concrete may be expected around the margin of the work. Placing concrete under water is a particular job. It will not do merely to dump the concrete into a deep pool and trust in Providence for the rest. The standard methods of depositing concrete under water are through tremies, in closed buckets, and in bags.

GENERAL REQUIREMENTS

Instructions for Concreting under Water.—In every case where concrete is to be placed under water, special directions regarding its composition and method of placing should first be obtained from the engineer in charge of the work. The inspector, of course, will be governed by the engineer's instructions.

Mixing Concrete.—The concrete should be a 1:2:4 mixture. Concrete deposited under water should be given an ample proportion of cement—in fact, it is well to use about 10 per cent extra cement, to allow for loss. The concrete should be of such consistency as to settle by its own weight. That of a quaking consistency is generally used. Concrete should be mixed long.

In all cases, or by whatever means the concrete is lowered, it should be allowed to take an initial set, losing to some extent its plasticity before being lowered through the water. Concrete that is mixed and allowed to stand several hours and then remixed again is preferable to freshly mixed concrete for placing under water, as the cement is partially set and is less liable to be washed out. It is sometimes argued, however, that the concrete loses as much strength by the disturbance of its setting when in what is termed the plastic state as by the loss of cement under ordinary conditions.

Dry concrete, i. e., a mixture of aggregates and cement without water, should not be employed in laying concrete under water.

Depositing Concrete under Water.—Concrete should not be deposited in foul or polluted water, as that containing sewage or discharge from pulp or paper mills, tanneries, etc., or refuse from any other washing processes. Such water coming in contact with fresh concrete will destroy it by attacking the setting cement.

Placing concrete through water should be carried on continuously to insure a perfect monolithic mass. Where concrete is not deposited continuously all sediment should be removed from the surface of

the concrete, by pumping or otherwise, before depositing fresh concrete. Concrete should be placed in as large batches as possible.

It is very important that concrete work be carried on continuously in muddy water; otherwise there will be formed layers of laitance and mud from $\frac{1}{8}$ in. to 1 in. or more in thickness, which are weak and will result in the settlement of the structure. On a certain piece of work the top of concrete which was used for sealing the bottom of a cofferdam, and which had been left for about two weeks before the cofferdam was pumped out, was found to contain a great deal of this class of rotten material. The bottom of the cofferdam at the top of the seal was very rough, and in the valleys, which varied from 2 to 3 ft. in depth, there was found about 6 in. of this useless material.

Concrete may be deposited successfully under water, if so handled as to prevent the washing of the cement. The concrete should not be dropped from any height over 6 in., but should be deposited and spread gently, without ramming, so as to prevent the separation of the ingredients and thus secure a homogeneous mass. Under no circumstances should it be permitted to deposit concrete by dropping it freely into water and allowing it to settle to the bottom. Mixed concrete if emptied loose and allowed to sink through water is destroyed. Dropping concrete through a depth of water will not only wash out some of the cement but will tend to separate the ingredients. Even a drop of a few feet causes the material to rearrange itself and settle with the heaviest part, such as the gravel or broken stone, at the bottom.

Great care must be taken not to disturb the water in which the concrete is being placed, nor to touch the concrete before it has set. It cannot be too strongly insisted that freshly deposited concrete must not be disturbed.

Spreading Concrete.—Care must be taken to keep the surface of the concrete approximately level by means of a rake or other suitable tool immediately after being deposited, in order to avoid the formation of pockets which will retain laitance as mentioned below. The inspector should insist upon the concrete being deposited in the allotted place in a compact mass and in a good and workmanlike manner. The concrete must not be rammed under water, as the stirring of the water will carry away cement. It should be wet concrete, so as to require no ramming.

Laitance.—When concrete is deposited in water, a pulpy, gelatinous fluid is washed from the cement and rises to the surface, appearing as a sort of milky scum. The French engineers apply the term "*laitance*" to this substance. It is a whitish, gelatinous substance which, while of about the same composition as the cement, has little or no hardening properties. (See also Art. 31.) Care must be taken to prevent the formation of laitance, which hardens very slowly and forms a poor surface on which to deposit fresh concrete. In fact, its presence on the surface of or adjacent to deposited concrete weakens the bond between old and new material. Laitance is formed in both still and running water, and should be removed before placing fresh concrete.

Detecting Wash.—The existence of "washing" in concrete deposited under water is shown by the rising to the surface of a milky scum, which, as mentioned above, is called laitance. The presence or absence of laitance indicates quite clearly the presence or absence of "washing."

Protection from Currents.—Where there are currents, a dangerous amount of washing may result after the concrete is in place. Concrete should never be placed in running water. The danger is that the cement coating will be washed off the sand and gravel particles, leaving the mass without a binder. In fact, if concrete is deposited with the utmost care, in closed buckets or through tremies, and there is any current to speak of, a considerable portion of cement is certain to wash out of the deposited mass. Placing concrete under water, therefore, involves the distinctive task of providing means to prevent the washing action of the water. It is also distinguished from work done in air by the fact that it cannot be compacted by ramming as mentioned above, but the main problem is that of preventing wash during and after placing. The only remedy in such cases is to deflect or break the current by shields or other means, and the means adopted must be determined for each case separately.

Where the concrete must be deposited in running water, it may be done by placing the concrete in bags and depositing the bags in place. Instead of bags for placing concrete, substantial forms or cofferdams may be used, so built as to prevent currents of water flowing through them when using tremies or buckets. Cofferdams should be sufficiently tight to prevent current through the pit, and the water in the pit should be quiet.

Care must be taken to prevent the cement from being floated away. The inspector should watch for trouble of this sort and promptly notify the engineer when it appears.

TREMIES, BUCKETS, BAGS, ETC.

Depositing through Tremie.—A tube of wood or a sheet metal funnel with a stem 12 or 14 in. in diameter and long enough to reach to the bottom may be used to deposit concrete under water. Such a tube is called a tremie. The method of operation is to fill the tube with concrete and then lower it into the water, removing the bottom by means of a mechanical arrangement, and thus allowing the concrete to come out gradually, while at the same time a new supply is shoveled into the top of the tube. Much care is required to secure a steady movement of the concrete.

The concrete should be mixed plastic, but neither dry nor wet—the former is liable to clog in the tube, and the latter flows out at the lower end too easily. In other words, if the concrete is mixed very wet the chance of "losing" the charge is increased, and if mixed too dry it is more liable to choke in the tube.

Care must be taken that the concrete has no fall through the water, but oozes out so as to cause a minimum disturbance of the

material. The tremie should be kept filled with concrete up to the top of the water level, and the discharge end should be kept buried in the freshly deposited mass, to prevent emptying, and raised a few inches at a time as the filling progresses. Every time the tremie is charged anew it results in washed concrete until the tube is again full. The tremie must be carefully moved back and forth so as to deposit an even layer over the area to be covered.

When necessary in passing under and around certain objects, curved adjustable lengths should be provided at the bottom of the tremie for depositing the concrete in places that would be otherwise inaccessible.

Depositing through V-Shaped Box.—In lowering concrete through water, a V-shaped box of wood or plate iron is often used. This apparatus is so built that by a lever or rope arrangement one side of the box will swing loose and allow the concrete to fall out. The box is then raised and refilled.

Depositing in Buckets.—There are numerous devices in the shape of buckets that are used for depositing concrete under water. The essential features of all of these buckets for depositing concrete are that the form be such that when the bucket is opened all of the contents may fall out, and also that the device for opening shall be such that it can be worked from above.

Where drop-bottom buckets are used, they should be filled on the mixing platforms and the tops closed and latched, so as to prevent the washing away of the cement in passing through the water. The buckets should be lowered vertically to the bottom as rapidly as practicable. They should not be dumped until the bucket is close to the point of deposit, so that the concrete will not fall through the water. The bucket should be carefully lowered to the bottom and raised to the surface, so as to cause as little disturbance as possible of the water.

Care must be taken to keep the deposited concrete as nearly horizontal as possible over the area to be covered. The placing of isolated piles of concrete must not be permitted.

Depositing in Pails.—In small work the concrete can be put in pails, boards placed over the pails, and when the bottom is reached, by turning the pails over, drawing the boards from underneath them, and raising the receptacles, the concrete is allowed to flow out.

Depositing in Bags.—Concrete may be deposited under water by enclosing it in paper bags and lowering or sliding them down an incline into place. The bags get wet and the pressure of the concrete soon bursts them, thus allowing the concrete to unite into a single mass. The paper bags should be placed in the desired position under water in such a manner that the bag or envelope is not ruptured until after or at the time it is in place.

Concrete is also deposited under water by enclosing it in open-cloth bags, the cement oozing through the meshes sufficiently to unite the whole into a single mass. Porous bags should be lowered rapidly through the water into place to reduce the time of wash.

Sometimes very large bags are employed. If loosely filled they

will flatten out after placing and will cement together more or less. The inspector should see that the bags are not filled too full to settle readily and closely together when piled in place. No delay should occur in the process of depositing which will permit concrete in place to become set before succeeding bagfuls are deposited. The delay between mixing the concrete and filling and depositing the bags should not be long enough to permit the concrete to have set.

GROUTING SUBMERGED STONE

Masses of gravel, broken or rubble stone deposited under water may be cemented into what is virtually a solid concrete by charging the interstices with grout forced through pipes from the surface. Grout has been forced through 2-in. pipes into depths of 50 ft. and over.

Mixing Grout.—The grout should be a 1:1 mixture of Portland cement and sand, with sufficient water to form a thick paste.

Art. 37. Cinder Concrete

Cinders are often made use of in concrete. The principal advantage of cinder concrete is that it is light in weight, being much lighter than stone concrete, as it weighs about 112 to 120 lbs. per cubic foot, while stone concrete weighs about 150 lbs. per cubic foot. It does not compare favorably with stone concrete on account of its inferior strength and because it is likely, in lean mixtures, to cause corroding of steel or iron. Concrete in which cinders are employed as the aggregate is always inferior in strength to broken stone or gravel, for the strength of concrete is governed by the strength of the aggregates. It is, however, lighter than rock concrete as mentioned above, when strong enough for the purpose intended. Cinder concrete should not be used where great strength is required. It is not adapted to reinforced work because it is so porous that it does not protect the steel from corrosion.

Cinder concrete may properly be used for filling vacant spaces and for certain parts of structures in which the stresses are very small. It is very useful in filling in between the sleepers in buildings and on the top of terra cotta arches. It may also be used in filling in the spandrel of stone or concrete arch. It is sometimes used for the construction of very light reinforced work, such as the floor or fire escape balconies and other work of this character. Cinder concrete may be easily cut or chipped, and nails may be readily driven into it with ease for a month or two after it has set—both of which qualities are additional reasons for using it for floors, particularly for the filling between the steel beams used in the construction of fireproof floors.

Cinders are used for concrete in fireproofing work, such as floors. If the cinders are well burned and free from lumps of coal, cinder concrete makes an excellent fire protection. Such concrete is light in weight and porous and a very poor conductor of heat or sound. Owing to the variable and unreliable character of the material it

cannot be recommended for structures in which strength is the controlling factor in the design. Its most valuable properties are its light weight and the resistance which it offers to heat. It is therefore used for fireproofing and light floor construction.

The danger of cinder concrete is that there may be too many ashes in it and therefore the concrete will not be good. There may be a great deal of unconsumed coal in the cinders, and this is a menace in case of fire. Certain coals have a high sulphur content. Cinder concrete made from cinders produced from such coal never stops expanding, apparently, and many buildings have been damaged from this cause alone. Sulphur attacks metal badly, so that reinforced cinder concrete made from cinders containing much sulphur will rapidly weaken.

Quality of Cinders.—Only clean cinders, and preferably those from the furnace of a steam boiler, should be used for making concrete. It is best to screen the cinders so that the concrete will not be made lean by the fine particles when mixed with mortar already containing sand. For properties of cinders suitable for concrete work, see Art. 11, page 122.

Proportioning Cinder Concrete.—The proportions commonly used are 1:1:3 and 1:2:5. Cinder concrete in the proportion of 1:2:4 is probably as good a protection for steel as stone concrete.

Mixing Cinder Concrete.—In using cinder concrete where steel reinforcing is entailed it should be mixed with an excess of fine mortar and very wet, so that the cement will be liquid enough to fill the little cavities in each cinder. Great care must be taken in the mixing and proportioning of the ingredients. A rich mixture of cement should always be required.

A wet mixture is most suitable for concrete made with cinders, owing to their porosity, so that the cement will be liquid enough to fill the little pores in each cinder. This precaution is indispensable when the concrete is to be used with steel, as otherwise the steel will be rapidly corroded by the action of air reaching it through the little cavities in the cinders. When concrete is mixed wet enough to puddle easily (see page 296), the cinders will work to the top, being lighter than the cement and sand. Especial care must be used when depositing this concrete, and the concrete should be just wet enough to shake like jelly in the barrow. When wheeled any distance, mix the concrete in the barrow before dumping.

Laying Cinder Concrete.—Cinder concrete should be rammed or tamped very lightly, if at all, as heavy ramming or tamping will break the cinders, leaving uncemented surfaces. It should preferably be puddled.

Art. 38. Asphaltic Concrete

Asphalt or tar concrete in which steam cinders or broken stone or gravel and sand are mixed with asphaltum or tar instead of cement paste is used to some extent for waterproofing and for lining reservoirs and constructing mill floors. Such mixtures differ in degree only from the mixtures used for asphalt street paving, for

discussion of which the various books on paving and asphalts should be consulted. Their most valuable properties are, imperviousness to water and elasticity.

Proportioning Asphaltic Concrete.—Asphaltic concrete may be composed of asphaltic mortar and broken stone or gravel in the proportion of 5 parts of stone and 3 parts of mortar.

Mixing Asphaltic Concrete.—The broken stone or gravel should be heated to a temperature of about 250° F. and added to the hot asphaltic mortar. The mixing is usually performed in a mechanical mixer. It may, however, be done with shovels on a board platform, the asphalt being poured over the stone. In making asphaltic concrete, care must be taken thoroughly to mix the asphalt and the stone. Each fragment of stone should be covered with asphalt; but more asphalt than enough to fill the voids is objectionable, since it increases the cost and decreases the strength of the mixture. Usually 10 or 12 gallons are required for a cubic yard of unscreened stone.

Laying Asphaltic Concrete.—The material must be laid hot and rammed until the surface is smooth. Care must be taken that the materials are properly heated, that the place where it is to be laid is absolutely dry, and that ramming is done before it chills or becomes wet. The rammers should be heated in a portable fire.

CHAPTER VII

INSPECTION OF SURFACE FINISHES FOR CONCRETE WORK

Art. 39. Imperfections in Exposed Concrete Surfaces

Exposed concrete surfaces frequently present a patchy or unsightly appearance. In fact, it is not such an easy matter to secure a smooth or even grain and uniform color on a concrete structure. In a very large majority of cases concrete structures are disfigured by a lack of uniformity in color, dark or light patches being conspicuously noticeable, while in other cases a streaky appearance is to be seen. The imperfections in the exposed surfaces of concrete are usually due to one or more of the ten well-known causes which may be summed up as follows:

1. Variations in the nature of the cement, sand and stone.
2. Lack of uniformity in the amounts of ingredients in each batch.
3. Insufficient mixing in any or all batches of concrete.
4. Lack of care in placing the concrete next the mold.
5. Lack of proper protection after placing concrete.
6. Efflorescence and discoloration of the surface.
7. Unsightly construction joints.
8. Imperfectly made forms.
9. Dirt on the forms.
10. Adhesion of forms.

Variations in Concrete Materials.—It is generally desirable that no change in the brand or quality of cement be made throughout the work. Different brands of cement may give different colors to the finished work. After a brand of cement has been accepted by the engineer and the contractor has purchased the same, no other brand should be permitted upon the work except by special permission of the engineer. The frequent changing of brands of cement is not only harmful to the work but also causes delay in testing. If more than one brand of cement is used the colors must be such as not to show marked variations in appearance of the completed work. Only one brand should be used at the same time in any section of the work, the idea being to prevent mixing of brands; but two brands may be used in succession on the same day. (See Chapter I, page 19.) Consideration should be given to some extent to seasoning, as a well-seasoned cement is less likely to cause craze cracking, shrinkage cracks or hair-checking than one which is fresh.

A more uniform color will always be obtained where some puzzolanic material is ground in with the cement, such as slag or trass.

This hydrated silicious material combines with the lime which has been liberated and prevents its washing out on the surface. The grinding of such material with Portland cement, especially where it is to be exposed to sea water, is highly desirable. The use of a small amount of lamp black in concrete will give a much more pleasing and uniform color than can ever be obtained with straight cement. (See page 392.)

All sand used in concrete that will be exposed to view should be of a bright, uniform color. No sand should be used for the outside finish of any concrete which contains small particles of coal or lignite, although sand of this character may be used in the interior portion of heavy pieces of concrete work. The sand used for concrete surfaces and for mortar facings should be clean and sufficiently coarse. It should be free from all foreign matter, excepting loam or clay, which may be permitted if the quantity does not exceed 3 per cent, and when these materials do not occur as a coating on the sand grains. (See Art. 8.)

Broken stone or gravel for exposed concrete surfaces should be clean and should be free from loam, clay, shale, and all perishable and foreign matter or other improper substances. It should be washed or screened, or both if necessary, to remove such substances. (See Arts. 9 and 10.)

The water used in mixing the concrete should be free from iron or other impurities that tend to discolor the concrete. (See Art. 12.)

Lack of Accurate Proportioning.—Lack of uniformity in the amounts of ingredients in each batch will cause imperfections in the exposed surfaces of concrete. The inspector should make certain that the specified proportions are accurately and uniformly adhered to. In this connection, see Art. 14, page 152.

Insufficient Mixing of Concrete.—Concrete should be thoroughly mixed and not allowed to look raw when deposited in the forms. If the concrete is not uniformly mixed, the surface will be irregularly colored and will contain pitted and honeycombed spots, with here a patch of smooth mortar and there a patch of exposed stone. Careful mixing will avoid this to a great extent. (See Art. 15.) It will readily be understood that where any excess of water is used, segregation of the coarse and fine particles will take place, with a resulting difference in color. Where a large amount of water is used the concrete is more porous and the very considerable percentage of free lime liberated from the Portland cement in the course of setting, is more readily brought to the surface at such a point. These results can be readily illustrated by shaking up the very wet mortar in a test tube and allowing it to subside and set. The amount of water in a concrete, the face of which is to be exposed, should be neither too small nor too large, but such a concrete should certainly not be dry or the exposed face will be honeycombed.

Lack of Care in Placing Concrete.—If the concrete is unmixed in the handling, the surface will be irregularly colored and will contain pitted and honeycombed spots. Imperfectly placed concrete will have here a patch of smooth mortar and there a patch of exposed

stone. Careful placing will avoid this to some extent. Spading forks should be used to pull the coarse stones back and cause the mortar to flush to the surface. (See Art. 41, page 384.) When airholes appear in the surface of concrete cast against a mold, there is an indication that the concrete has not been properly tamped. Thorough tamping is absolutely essential to securing good concrete and a smooth surface. In this connection, see Art. 25, page 298. Surface coatings can be used to cover up any defects. (See Art. 44.)

Pock marks (blotches or pippings in the smooth surface of mortar) are caused by the incorporation of air or water or foreign matter, which in the process of setting are forced to the surface.

Lack of Proper Protection of Concrete after Placing.—It is useless to make good concrete and place it properly, unless care is taken to protect it until it is hard enough to take care of itself. All exposed surfaces of finished and unfinished concrete should be kept constantly moist by sprinkling with clean water at short intervals. An excellent practice is to cover the surface with burlaps which may be kept saturated. This not only furnishes the necessary moisture but protects the work from the direct rays of the sun. Rain falling on green work will make it rough and unsightly. Too rapid drying is apt to result in hair-checking or map-crazing. These hair cracks may usually be prevented by keeping the surface wet for a considerable time. (See Art. 29, page 335.)

The appearance of a concrete surface can be modified somewhat by the treatment it receives while hardening. If it is allowed to dry rapidly it will be of a lighter color than if kept damp and cool and allowed to dry slowly, also the former surface will be more dusty than the latter.

For a spaded or mortar face finish, extreme care should be taken to protect the surface from danger of injury by frost. A thin scale about 1/16 in. or more in depth is apt to scale off from mortar facings which have been frozen. This, of course, is objectionable where a smooth finish is desired. In no case should fresh manure be placed over very green concrete to protect it from freezing, as it will spoil the surface of the concrete. (See Art. 33, page 361.)

Efflorescence and Discoloration of the Surface.—If the concrete is not water-tight, and particularly if there is water or earth against the back of the concrete, efflorescence, or a white (or a yellow) coating on the surface, is likely to appear. Efflorescence results from diffusion of soluble sulphates of lime and alkalis to the surface. In other words, it is due to water percolating through the concrete and dissolving the soluble salts, which are left as a white or yellow powdery substance on the surface when the water evaporates. Efflorescence tends to disappear in time, and rarely is sufficient in amount to cause any complaint. For causes, prevention and removal of efflorescence, see Art. 31, pages 342, 345 and 346.

The presence of iron in the water or the material of which concrete is composed sometimes causes the appearance of small brown spots, like smallpox pits, on the surface of the concrete. Where there is any doubt as to whether or not there is iron present,

the suspected material should be sent to a good laboratory for analysis and report. Sulphate of iron is sometimes encountered in certain cements; this causes dirty brown spots to appear in the work from the oxidation of the iron. Underburned cements also often produce the same results.

Blemishes which appear when the forms are removed should be corrected while the concrete is green.

When concrete surfaces are discolored as a result of smoke, soot and similar impurities, it is sometimes possible to remove the accumulation by applying naphtha. If this fails, a light application of sand-blast will entirely remove the discolored surface. (See page 405.)

Unsightly Construction Joints.—All concrete work should be finished in its entirety before shutting down, but when this is not possible the resulting joint should be formed where it will least impair the strength and appearance of the structure (see Art. 26). If the placing of the concrete does not proceed continuously day and night, an unsightly line on the surface is likely to show where the two days' work joined. In fact, the most noticeable imperfection in concrete surfaces is the lipping between consecutive days' work. The stiffer the forms, the less the lipping. On account of this lipping, each day's work should be brought to a horizontal layer by using a straight edge. Care must be taken in the location of and in the manner of constructing the resulting joint if the concreting does not proceed continuously.

If the appearance of the finished face is of importance, special care must be exercised in order to prevent unsightly construction joints. Unsightly lines on the surface may be almost entirely eliminated by nailing a bevel or triangular strip against the form and finishing the day's work to the inner edge of this strip, thus producing a regular groove instead of the usual ragged division line. The author has observed in a great many concrete structures that where one day's work joined that of another, unsightly construction joints could be very easily noticed, and in some cases these joints or lines were inclined at about the angle of repose of the wet concrete.

Imperfectly Made Forms.—Some of the precautions that must be taken to secure a good finish to the face of concrete work have already been mentioned in considering the forms (see Chapter IV, page 197.)

In well mixed and placed concrete the film of cement paste which flushes to the surface will take the impress of every flaw in the surface of the forms. In fact, all the defects in the form work will show on a flat concrete surface; in addition, all defects in the concrete will show. It will even show the grain marks in well-dressed lumber. From this it will be seen how very difficult it is to mold concrete that the surface will not bear evidence of the mold used. It is difficult if not impossible to make perfect forms, and the degree of perfection to which it can be carried depends upon the workmanship expended in form construction. Forms with a smooth and even surface are difficult and expensive to secure. It is impracticable, in the first place, to secure lagging boards dressed to exact thickness,

and in the second place it is impracticable to secure perfect carpenter work. Joints cannot be got perfectly close, and a nail omitted here and there leaves a board free to warp. It is practically impossible to maintain the forms in perfect condition, because the water in the concrete is absorbed by the wood in the forms, causing swelling and warping. From this point on the use of imperfectly sized lumber, careless carpentry and poor maintenance can go to almost any degree of roughness in the form work. Only approximately smooth and unmarked concrete surfaces can be secured in plain wooden forms, and this only with the very best kind of form construction. So much for the limitations of form work in the matter of securing surface finish. These limitations may be reduced in various ways.

Joint marks may be eliminated wholly or partly by pointing the joints with clay or mortar, or by pasting strips of paper or cloth over them, or the whole surface of the lagging can be paper (see page 204); by the use of oiled paper there will be little trouble from the paper sticking. If the joints between the individual boards of the forms are not eliminated, the concrete will run between the boards and have an ugly fin on the exposed surface. Swelling of lumber in forms will throw the face of the concrete out of plumb. The appearance of corners in the concrete may be improved by bevel strips within the forms (see page 210). Knotholes in forms should be properly plugged with clay. Forms which are imperfectly constructed with different thicknesses of lumber used indiscriminately will not produce results which are compatible with ordinary conditions. Grain marks and surface imperfections can be reduced by oiling the lumber so as to fill the pores, or by first oiling and then filling the coat of oil with fine sand blown or cast against the boards. (See Art. 18, page 242.)

The preceding remarks are, of course, based on the assumption that as nearly as possible a smooth and even surface finish is desired. If something less than this is sufficient, and in many cases it is, form-produced surface defects become negligible in the proportion that they do not exceed the standards of roughness and irregularity considered permissible by the engineer; as these standards are individual with the engineer—what one considers excessive roughness and irregularity another may consider as amply even and smooth. The inspector, of course, will be governed by the engineer's instructions in regard to the standard of roughness allowable. The point that the inspector should keep in mind, however, is that beyond a certain state of evenness and regularity form-produced surfaces are impracticable to obtain, because to construct forms of the necessary perfection to obtain them costs far more than it does to employ special supplementary finishing processes as described elsewhere in this chapter. In other words, the inspector cannot be too exacting in the construction of form work.

If a finished piece of work is desired, the board marks must be either concealed or erased. In the first case, the concrete work is faced with various materials, such as brick, terra cotta, plaster, etc.;

in the second case, the surface itself is improved by tooling, rubbing or brushing.

Dirt on the Forms.—Surface blemishes due to dirt or cement adhering to the form boards have no excuse if the contractor cares to avoid them. All dirt or cement must be removed from the forms just before placing the concrete. It is a simple matter to keep the forms clean and free from such accumulations. All forms having been previously used should be thoroughly cleaned and prepared before being used again. A soiled surface may be cleaned by washing with water and a scrubbing brush while the concrete is still green. If the concrete has set too hard for washing, rubbing with a piece of wood or brick will remove the dirt if plenty of water is used (see page 239). A very unsightly face is often produced by leaving the mortar on the forms, which has resulted by the throwing of concrete into the forms in the previous day's work.

Adhesion of Concrete to Forms.—Concrete surfaces are frequently impaired by the adhesion of the surface to forms, owing to proper provision not being taken to prevent it. Many different methods are employed to prevent this adhesion, as described in Art. 18, page 239.

Art. 40. Finishing Concrete Surfaces

Since the character of a concrete structure is judged largely by the appearance of the exterior, the finishing of such surfaces becomes very important. In some structures the appearance is the most important part of its design and construction.

Treatment of Concrete Surfaces.—There are various ways of correcting the defects or imperfections in exposed concrete surfaces, mentioned in Art. 39, or of securing a surface of better appearance than any left by the most perfect forms. These will next be considered, attention being given first to the methods of finishing a plain, smooth surface, and then to the methods of finishing that secure a more ornamental surface. Except for the crudest work, all concrete surfaces should be treated. The finishing of a concrete surface may at first seem a matter of little consequence, but it is really one of great importance and requires the most careful consideration. The matter of exterior finish should be planned out before any concrete is poured above grade, and will be governed by the size and class of the structure and the style of architectural decoration, if any.

Specifications for Surface Finish.—Specifications should be particular and explicit regarding the character and nicety of the surface finish required. If they are not, the inspector should learn from the engineer the quality of work he has in mind and should see that the contractor clearly understands the requirements.

Careful Inspection Needed.—Perfection of surface finish is a matter of attention and skillful workmanship, and the inspector has chiefly to watch the workmen. This class of work should be classed as requiring skilled labor, but too often it is slighted and reliance placed on plastering the concrete afterward.

Classes of Finishes.—Finishes are of two classes: (1) Those in which the molding is so done that the finish is a part of the molding process; (2) those in which the molded surface is treated after the forms are removed. Faults in finishes of the first class must be prevented during molding by careful workmanship, for after the concrete has once set they can be remedied only by patching, which is generally very unsatisfactory, or by giving the whole surface one of the finishes belonging in the second class.

Types of Finish.—The above two general classes of finish for concrete may be further divided into the following types or methods of treatment:

(1) Plain, spaded, mortar face and troweled finishes. (Art. 41.)

(2) Introduction of various ingredients into mortar or concrete. (Art. 42.)

(3) Removal of surface in various ways. (Art. 43.)

(4) Coating surfaces in various ways. (Art. 44.)

(5) Other methods of exterior finish. (Art. 45.)

Art. 41. Plain, Spaded, Mortar and Troweled Finishes

Plain Finish.—In some structures, where the appearance need not be regarded, the concrete can be left just as it comes from the forms, and if sufficient care has been taken in building the form work and placing the concrete, a very satisfactory finish will result. Care must be taken to avoid noticeable voids or stone pockets. Such treatment will result in a sandy finish.

Dry Surface Finish.—A dry surface finish may be obtained by using a fine stone in the aggregate, mixing fairly dry, and not spading the concrete next to the forms. The theory of dry concrete is that the imprints of joints and other form marks are not readily received by it. (See page 188.)

SPADED FINISH

Spading the face of the concrete to secure a finish gives good results if the work is carefully done, and no washing of the wall with grout or plastering should be required. This class of work should be classified as requiring skilled labor, but too often it is slighted and reliance placed on plastering the concrete afterward. In the author's opinion, this method is superior to any form of mortar facing. It is easier and cheaper, is equally effective, and the face does not check or crack. A mortar finish does both, in the course of time, permitting seepage and discoloration of the face of the concrete. Reinforced walls 20 ft. high have been finished in this manner and no other treatment was needed.

Preparation of Forms.—The method of spading is applicable only where forms are used. Necessarily, therefore, imperfections in these forms are to be carefully avoided. The smoother the forms for this class of work, the better will be the appearance of the work. (See page 381, and also Art. 17.)

Consistency of Mixture.—Where spading is faithfully done, an

absolutely smooth surface is generally the result, whether the mixture be dry, medium or very wet. A very wet mixture will reveal the exact nature of the forms in great detail, including all defects and faults of surface and workmanship. If the surface finish is of importance, the drier mixtures are preferable. In the case of a dry mixture, however, spading must be done with greatest care by experienced workmen, in order to get uniform results; but with a medium or very wet mixture it is very easy to obtain good results. With a wet mixture spading is generally required only as an added precaution against the possibility of voids in the face of the work, and is really necessary in few cases.

Spading Concrete.—Especial care should be taken to thoroughly spade the concrete against the forms, in order to prevent pitting. Great care must be taken to avoid straining the forms or displacing the reinforcing rods while spading the concrete. (See page 297.) In other words, be careful not to pry with the spade while spading, as this is apt to spring the forms. Skilled and experienced workmen should be assigned to do the spading.

Tools for Spading Concrete.—Spading is best done with a special flat-bladed spade, having the blade punched or perforated with several large holes or slots, which will screen back the stones and allow the mortar to pass and thus cover every stone. In other words, the fine material will quickly flow in behind the spade, and a smooth surface will be secured. In narrow forms, instead of a spade a common garden hoe may be used, with the blade bent nearly in line with the handle. For reinforced work where the spading must be done in a space of 2 or 3 in., this tool is particularly useful. On high reinforced walls which must be spaded from the top, long handles are required. It is well to have these tools with different lengths of handles, the shorter ones being used near the top.

MORTAR FACE FINISH

Where a surface finish of fine texture or of some special color or composition is desired, the concrete is often faced with a coat of mortar, or, sometimes, neat cement paste or grout. This facing often receives a future special finish as described in succeeding paragraphs, but it is more usually used as left by the forms, or, at best, with only a troweling or brushing with grout (see page 406). Mortar facing is not an easy job and requires workmen well experienced in this class of work. The contractor must not continually change the facing hands who are skilled in this class of work. The uniformity of the appearance of concrete work is desirable, and is dependent largely upon this class of labor.

All mortar for face work should be made by hand or a regular mortar mixer.

Methods of Obtaining Mortar Face Finish.—If a mortar (or a granolithic) finish be specified, it may be obtained by placing the facing mortar and concrete backing at the same time and tamping them together. The certainty of a bond is in this manner assured.

The facing material may be applied to the forms just ahead of the backing, which is placed against and rammed into it. Moldings, cornices and other ornaments requiring mortar face should be formed by spreading plastic mortar upon the interior of finely constructed molds just as the concrete is being laid. (See Art. 54.) This process requires constant watching to see that the plaster coat does not slough or peel off before it is backed up with the concrete.

Another way to obtain a mortar finish is to place a loose board against the forms and tamp the concrete behind the board. The board is then removed and mortar run into the space that it occupied. This method is only applicable to comparatively dry concrete backing.

A modification of the above method consists in pushing the concrete back from the form and pouring the space full of grout. The concrete is placed and tamped in 6- to 8-in. layers, then a common gardener's spade is shoved down between the concrete and the form and the concrete pulled back about an inch and the opening poured full of grout and the spade withdrawn. If this work is carefully done there will be very few stones showing when the forms are removed.

Still another method of obtaining a smooth surface is to use a very wet concrete and throw it violently against the form, so that the aggregates rebound, leaving in effect a mortar facing. This is, however, not to be recommended for fine work, as the forms are apt to be indented and the alignment impaired, but ordinarily this method is effective.

A fifth method of using granolithic plates or metal facing forms will be described later.

Tamping Mortar Face and Concrete Backing.—The mortar (or granolithic) finish should be maintained between the concrete and the face form in a thickness of about 1 inch. The inspector, of course, will be governed by the thickness given in the specifications, or in the absence of such information he will be governed by the engineer's decision in the matter, provided a mortar facing has been specified. Care must be taken that the concrete is rammed into and perfectly united with the mortar facing. The tamping or ramming, however, must not be so hard as to force pieces of stone through the facing, but just hard enough to bond thoroughly the facing and backing. The facing should show a smooth, dense surface without pits or irregularities. This is most likely to be secured by thorough and systematic ramming.

Use of Granolithic Plates or Metal Facing Forms.—Possibly the best method of placing the facing material consists of what might be called a metal facing form or mold, constructed and used as follows:

The metal facing form or mold for placing the facing material on vertical surfaces generally consists of short lengths of iron plates 8 or 10 in. wide and about 6 ft. long, with three angle irons riveted to each plate, the size of the angle depending upon the thickness of the facing material specified (see Fig. 26). The metal facing form, however, may be any convenient width and length, depending on the

nature and size of the work. An angle is placed at the center and one about 6 in. from each end of the plate, one edge of which is provided with handles and slightly flared to assist in depositing the material.

The metal facing form is placed against the wall form with the handles up and the angles tight against the form. The space between it and the back of the wall is then filled with ordinary concrete backing of the specified proportions and the space between the metal form and the face form filled with facing material or mixture. Several of these metal forms may be used in line, with their ends lapping, and smaller lengths used to fill out a given length of wall form. Some difficulty may be experienced in carrying up a long line of this kind of concreting, especially at corners and at the junction of two plates. It cannot be worked well in a narrow space.

The facing mortar should be kept slightly higher than the backing, to prevent the backing from running forward and disfiguring the front surface. Care must be taken that the metal facing form is not permitted to remain until initial set takes place, but be frequently jarred and raised at short intervals to prevent the formation of shuts and seams and air spaces between mortar and the concrete. A trowel should be worked rapidly along the form,

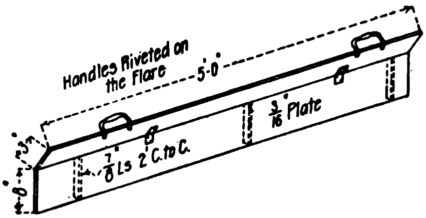

Fig. 26. Type of Metal Facing Form.

to remove air bubbles. The author has found that if extreme care is not taken the steel plate will drag, leaving an unreasonably large space between the concrete and the mortar facing; and if the rammers are not particularly careful there will be no bond between the two and the mortar facing will flake off. Perfect success is secured only at the expense of great care. The facing mortar should be mixed wet and in small batches. Care must be taken to keep the forms perfectly clean, or discoloration will be the inevitable result. A mortar facing shows the impress of small roughness on the form more readily than does concrete, and particular care is necessary to secure a smooth surface on the form when a mortar facing is adopted. Even the grain of smoothly dressed wood is clearly impressed on the plastic material.

Proportions for Mortar Facing.—The facing mixture should not be of too rich proportions, in order that surface cracks may be avoided. As to the richness of the mortar facing, two parts sand by measure to one volume of packed cement is usually sufficient, though

a more glossy finish may be made, if desired, by using equal parts of cement and sand. Good results, however, may be obtained with mortar composed of one part of cement to three parts of sand or screenings. The author does not recommend mortar richer than a 1:2 mixture. It is better to avoid too great a variation between the richness of the mortar used for facing and that used in the body of the concrete. Too rich a mixture, or a surface mixture richer than the body concrete will cause hair cracks.

Crushed marble screenings may be used if obtainable. These screenings or sand must not be too fine and should not exceed 1/4 inch. Limestone, granite or other stone screenings, different colored gravels, and sand may be substituted for the marble chips. (See Art. 8.)

Proportions for Granolithic Finish.—Granolithic is a facing or surfacing mortar composed of crushed granite and cement. A granolithic finish is more frequently used for foot walks and other places where resistance to wear is required, but may be used to surface walls, to line reservoirs, etc. (See Arts. 51 to 53.) If a granolithic finish or surface is specified it may be made by placing against the face forms in advance of the body concrete—or, in case of horizontal surfaces, on top of the concrete base—a fine granolithic or facing concrete composed of one (1) part of Portland cement, one and one-half (1 1/2) parts of coarse sand, and two and one-half (2 1/2) parts of pebbles or crushed granite, or other approved stone as may be selected, screened to pass 1/2-in. and be retained on 1/4-in. screen, thoroughly mixed and soft enough for full flushing. The granite is sometimes specified to contain no particles larger than 3/8 to 1 in., and about one and one-half to two parts are to be used to one volume of Portland cement. Where both fine and coarse aggregates are used in the mixture for the facing material, a 1:1 1/2:3, or 1:2:3, or even a 1:2:4 concrete, with Portland cement, sand or stone screenings and crushed or screened gravel, may be used.

Thickness of Mortar Finish.—The thickness of mortar facing employed in practice varies from 1/2 in. to 3 in., but the usual practice is to make it 1 in. to 1 1/2 in. thick. There is more danger, perhaps, of making the mortar facing too thick than too thin, thereby using too much cement.

Thickness of Granolithic Finish.—Granolithic finish when applied to a concrete base should be laid at the same time as the concrete and should not be less than 1/2 in. thick for floors, 1 in. for sidewalks, and 2 in. for concrete pavements. In this connection, see Arts. 51 to 53. Do not attempt to put a top coat less than 2 in. thick on a set concrete base, and even then be prepared to see unsightly cracks on the surface.

Consistency of Mortar Facing.—The mortar facing for vertical surfaces should be mixed rather wet, since it must completely fill the metal facing mold; but care must be taken not to have it too thin, or the stones from the concrete behind will be pushed through it during the subsequent filling and ramming. The facing mortar must be carefully mixed. Also, since the facing cannot proceed faster than the backing, the mortar has to be mixed in small batches, so that it

is always fresh. Mortar facing or finish on an exposed horizontal or nearly horizontal surface should be mixed to a plastic consistency and should be put on immediately after the concrete is deposited, care being taken that the surface of the concrete is clean.

Dry Concrete Facing Mortar.—The ordinary facing mixture of mortar or cement as described above is so fine-grained and plastic that it readily takes the impress of every irregularity in the form work. Where a particularly good finish is desired, this makes necessary subsequent finishing treatments. To avoid these subsequent treatments and at the same time to reduce the form marks, a mixture consisting of 1 part Portland cement, 3 parts fine limestone screenings, and 3 parts ¾-in. crushed limestone has proved most satisfactory. These materials should be mixed quite dry, so that no mortar will flush to the surface when rammed hard. The theory of dry concrete facing is that the imprints of joints and other form marks are not readily received by it. In fact, with moderately good form work the imprint of the joints is hardly noticeable, and grain marks do not show at all. For thin building walls the above mixture may be used throughout the wall, but for more massive structures it should be used only for the facing and placed in the same manner as that described above for ordinary mortar facing.

Colored Facing Mortar.—A colored facing mortar may be obtained by using a suitable colored aggregate or by mixing coloring matter (mineral pigment) in the mortar. The first is the better, since it gives a durable color and does not injure either the strength or durability of the mortar facing. Introduction of various ingredients into mortar or concrete is discussed very fully in Art. 42.

SPADED AND TROWELED FINISH

The scope of this method is limited to instances where the forms may be quickly removed, or removed in sections. The edges of copings, etc., can be rounded by edging tools such as are used for finishing concrete sidewalks (see Art. 51).

Spading and Troweling.—The coarse aggregate should be well pushed back from the face of the form to allow the mortar to flush to the surface in a manner similar to that described for a spaded finish, on page 384. The forms must be stripped while the concrete is still green enough to be worked with a trowel. The surface should be troweled hard and smooth; but excessive troweling is likely to cause innumerable hair cracks in the finished surface. In this connection, see pages 426, 484 and 486.

WETTING OF FORMS AND MAKING GOOD DEFECTS IN SURFACE FINISH

Wetting of Forms.—Forms must be properly treated either for a spaded or a mortar face finish. Concrete or mortar will adhere very strongly to forms if no special provision be taken to prevent it. Many different methods are employed to prevent this adhesion, as are described in Art. 18, page 239.

Making Good Defects in Surface Finish.—With all the means used to cover up the irregularities in forms and make the surface smooth, there will still be some roughness not commercially avoidable. Some treatment of the surface after the removal of the forms is generally necessary. Noticeable voids, or stone pockets, should be filled with mortar mixed in the same proportions as the mortar in the concrete. Mortar for patching irregularities and pockets in concrete work must contain the same proportions of cement and sand as the concrete, or it will set a different color. Corners may break off in removing the forms. These should also be plastered (see page 341). A patchy surface may show that a bad batch of concrete was used, or that the concrete has been mistreated during setting. It has been found, however, that patches appear even where care has been taken to use the same cement and a uniform mixture. For methods of patching and repairing defective concrete surfaces, see Art. 30, page 338.

Art. 42. Introduction of Various Ingredients into Mortar or Concrete

DIFFERENT SIZED AND COLORED AGGREGATES

If a permanent colored concrete surface be desired, it may be obtained by properly finishing a surface faced with a mixture composed of Portland cement and an aggregate of the proper size and color. The surface must be scrubbed, sand-blasted, or otherwise treated so as to expose these aggregates. Obviously, if special effects are desired with this course of treatment the concrete must be deposited with exceptional care. (See Art. 43, page 397.)

Selection of Colored Aggregates.—The colors obtained by the selection of colored aggregates are perhaps the most agreeable and are doubtless more durable than those obtained from artificial coloring matter. By varying the kind, size and proportions of the aggregates, surface finishes of practically any desired color and texture can be obtained, the possibilities being limited only by the number of different aggregates available and the combinations of same. Pebbles, burnt clay, or broken brick, white marble chips, blue trap rock, other colored marbles, etc., together with the gray matrix of the cement mortar, can be combined to give almost any desired combination of colors and surface effects, thus giving an animated texture to the otherwise leaden and lifeless material. Powdered glass, marble, flint, alabaster, and metal filings can be effectively employed for coloring concrete surfaces by mixing with the cement used for the surface coat. A great variety of finishes may be produced by using gray trap rock, red and black granite and limestone screenings, black and white marble chips, different colored pebbles, yellow sand, brick dust, etc. The range of color in the aggregate is limited to the colors found in natural stone or other substances.

Using Silicates as Coloring Agents.—There are a number of colored aggregates in the various colors of silica sand. These are a

flint or quartz-like sand or rock, usually formed by impurities in silicic acid, or silex, as it is found in nature, which constitutes flint, quartz and most of the sands and sandstones. Red, brown, yellow, orange, purple and pink sands, all finely ground, have been employed for coloring cement surfaces, but if too fine or in large quantities they weaken the surface; and if coarse-grained they possess little coloring effect, because the particles are liable to show singly, causing a spotty appearance, or the cement entirely covers the surface of each particle of sand. When properly used, however, these colored sands form a most excellent means of coloring concrete to almost any shade desired.

Use of Ordinary Portland Cement and Aggregates.—Various shades and colors can be obtained by the use of different cements; for instance, a blue cement used in connection with light-colored sand will produce a light blue surface. One point often overlooked by the average worker is the fact that ordinary Portland cement varies from a light to a dark gray color; when employing this with any of the light-colored sands, as yellow, orange, pink, and even purple, it demands a large amount of the colored sand to produce the tint desired.

Use of White Cement and Aggregates.—If white cement is employed, the coloring agent is not handicapped by the color of the cement as mentioned above; thus a purer and more satisfactory tint may be secured with less of the material. This permits white sand or any sand of a neutral color to be mixed with the silica sand and the white cement, and yet produce a pure shade of the desired hue with a less proportion of the coloring material. A mixture of more than 1:3 should not be used unless it is absolutely necessary in order to secure the desired shade. (See page 488.)

A white concrete surface may be obtained by mixing one (1) part white Portland cement with two (2) or three (3) parts coarse white sand or marble screenings and applying the mixture as a finishing coat or mortar facing (see page 385). After the coating or mortar facing has set hard it should be washed off with dilute sulphuric acid, 1 part acid to 5 parts water (see page 401). The acid solution should be applied by painting on with a brush two or three successive coats and the surface then washed with plenty of clean water. White pebbles of various sizes can also be employed, and the aggregate may be anything from the size of coarse sand to that of pieces an inch or more in diameter. White sand or marble dust used in making concrete gives the finished work a lighter color than is obtained by using ordinary sand.

COLORING MATTER

Mineral coloring matter mixed in mortar is sometimes used to give a uniform color to concrete surfaces, especially where a permanent colored surface is not desired. In fact, it is not absolutely permanent and will grow lighter in color or tint after years of exposure. It is much easier to produce color effects by employment

of stucco than by endeavoring to produce colored cement or some coloring compound in the mortar of the mass concrete work. If used in the entire body there is a waste of material in that which is not exposed, and it is difficult to get uniformity by any other means, unless it is a case where plastering is permissible. Strength is gained and expense saved by using the colored cement for the surface coating only, not exceeding 1 in. in depth with the colored mortar used. Either for facing mortar or mass work, however, coloring materials have been successfully employed, the dry mineral color being added to the Portland cement before mixing.

Colors are often used in mortars to effect contrasts or to subdue the glaring tone of cement in sidewalks or in similar situations. Physicians have claimed that the great prevalence of ophthalmia and other forms of weak eyes is frequently due to the blinding glare from cement paved walks and limestone paved roads. At any rate, it is well known that uncolored pavements are very taxing on the eyes during bright, clear weather. A little lampblack can be used to advantage in ordinary concrete to relieve the dirty color of the concrete by giving a much more pleasing and uniform color than can ever be obtained with straight cement. It is commonly employed in cement sidewalks, changing the color of cement to gray, or slate (see page 488).

Coloring matter may be added to the cement to produce imitation building stones of red, terra cotta, brown, or slate colors. The effects in the red and brown sandstones are imitated so perfectly that it requires close inspection to detect the artificial from the natural stone. The artificial stone, however, is more durable and stronger than the natural stone. Experiments should be made with the various sands and cement to be obtained, so as to know what colors of stone can be produced without the addition of coloring matter as mentioned at the beginning of this article.

Selection of Coloring Matter.—Coloring matter should be used with caution, as its effect on the cement has not yet been very definitely determined. There is a danger of the setting properties of the cement being injured. In other words, coloring matter should be used sparingly, as much of it is detrimental to the setting of the cement. Care must therefore be taken in the selection of the coloring matter. The quantity and quality of the coloring matter must be such as not to impair the strength of the concrete. Certain pigments are known to be injurious; for instance, red lead, the pigment of the paints used for coating ironwork, is, even in minute percentages, decidedly bad for concrete.

The coloring matter must not contain acids, and must have no effect upon the alkalis of the cement. Coloring matter containing acids will attack the alkaline substances in cement and destroy it. Vegetable colors should never be mixed with cement. Vegetable or oil colors destroy or impair the strength of the cement. In other words, don't use artificial coloring matter containing oils, grease or acids. Only those coloring materials should be employed which consist of the oxides of the various elements, since the salts are

liable to disintegrate. Dry mineral colors seem to be the only ones that can be used, as apparently all liquid coloring matter destroys the cement, and even some of these are injurious to the action of the cement. They are the safest to use, however, as they affect cement the least, although, with the exception of ultramarine, which contains much silica, all coloring materials reduce the strength and durability of cement mortar to a greater or less degree. Ultramarine in small quantities seems to strengthen the mortar slightly. Other coloring matter should be used in moderate quantities.

Almost any color may be produced by mixing the right mineral coloring matter with the mortar facing or the concrete body. Most substances, however, are bleached by the cement and are of short life. Bright colors are difficult to obtain and would not be in keeping with a masonry structure, except in architecture. The following colors have been used without any apparent injurious effect upon the cement: Lampblack (boneblack), Prussian blue, ultramarine blue, yellow ochre, burnt umber, and red iron ore. The iron oxides and ochres are used for all shades, ranging from yellow to red and brown; manganese dioxide and lampblack for grays, slates and blacks; and ultramarines for the greens and blues. Manganese dioxide is better for slates and blacks than lampblack, as the oil in the latter affects the strength of the mortar. Some of the red oxides range in color from scarlet or Turkey red, gradually deepening to chocolate. Some oxides contain 95 per cent of pure ferric oxide, which is made from copperas, or, scientifically speaking, sulphate of iron. This is a by-product and is frequently evolved from waste acid liquors at tinplate works. This kind of oxide is far more suitable for coloring concrete than ochres and most of the earthy oxides.

Earthy colors, like Venetian red and umber, soon fade and have a sickly appearance. Common lampblack and Venetian red should not be used, as they are liable to run and fade. Red lead is injurious, even in so small quantities as 1 per cent, and greater amounts should never be used. The author does not recommend the use of red lead at all, as it weakens the mortar.

Germantown lampblack is more frequently used than any other coloring matter, and gives a bluish gray or stone color of intensity varying with the amount used. In fact, it is a good material to use on account of the small quantity it is necessary to use to secure a good color. It is of the utmost importance that lampblack for concrete work be practically free from oil, because a greasy lampblack is very hard to mix in a watery compound.

Sometimes a very white surface is desired. White cannot be produced by adding a coloring matter. A white cement should be used as mentioned on page 391.

All coloring materials should be the best to be obtained and should be used carefully, just enough being used to give the desired shade. It is good practice to use the colors that are now manufactured for this particular purpose from a base of iron pigment. These colors may be purchased in the open market. They are backed by

reputable manufacturers, from whom directions for their use may be obtained.

Use of Hydrated Lime.—Hydrated lime when added to Portland cement makes the color of the finished product lighter. When work is well done and well finished the color should be a light gray. By the addition of about 10 per cent lime the color is lightened several shades, and this addition is particularly useful in overcoming any darkening color in the sand. (See pages 391, 428 and 522.)

Samples of Colored Mortar.—Sample specimens containing different proportions of the specified coloring matter and of Portland cement should be made and allowed to become quite dry before being submitted to the engineer for approval. It will be the duty of the inspector to see that these samples are properly prepared. In any large work where the use of coloring matter is desirable and there is not time to properly prepare samples or to institute thorough tests, the advice of a cement chemist should be sought. Samples of colored mortar will go a long way by indicating just what colors may be used without detriment to the work. It is cheaper to prepare samples of colored facing mortar beforehand than to cut out work already done.

Proportioning Coloring Matter.—The following list indicates in general the effect of the most common coloring materials on cement mortar, the amounts named being added to a bag of Portland cement containing about 95 lbs. The proportions given should vary according to circumstances, different materials giving different colors. The precise shade obtained in any case will of course depend also on the color of the cement and the color of the sand.

Color Desired.	*Ingredients Used.*	*Quantity per sack of Cement.*
Black	Excelsior Carbon Black	2 lbs.
Black	Manganese Dioxide	12 lbs.
Blue	Ultramarine Blue	4 to 5 lbs.
Brown	Burnt Umber	4 lbs.
Brown	Brown Ochre	4 to 6 lbs.
Brown	Roasted Iron Oxide	6 lbs.
Buff	Yellow Ochre	3 to 4 lbs.
Gray	Germantown Lampblack	½ lb.
Green	Ultramarine Green	5 to 6 lbs.
Green, Light	Prussian Blue	¾ lb.
Pink	Venetian Red	4½ lbs.
Purple	Princess Metallic	5 lbs.
Red	Raw Iron Oxide	5 to 10 lbs.
Red, Bright	Pompeiian or English Red	5 to 6 lbs.
Red, Sandstone	Purple Iron Oxide	6 lbs.
Violet	Violet Iron Oxide	5 to 6 lbs.
Yellow	Yellow Ochre	5 to 10 lbs.
White	Lime, White Sand and Marble, also a mixture of Lead and Zinc Salts with Calc Spar will give very light surfaces	

It will be seen that any desired color may be obtained by varying the proportion of mineral coloring matter. The dry mineral colors, mixed in proportions of 1 to 10 per cent of the cement, give shades approaching the color used. The quantity of oxide to be added to the cement depends upon the strength of the oxide. Some are much stronger than others. Five per cent of a strong oxide will generally impart a close resemblance of the desired color to the concrete, but a

weak oxide will require from 10 to 15 per cent, and even 20 per cent, to obtain the same color.

Usually any coloring matter lessens the strength of the mortar and causes the surface to flake, and therefore no more should be used than is absolutely necessary, especially of the ochres. Sometimes, however, this loss of strength in the mortar is not very important, since the coloring matter is used only in the mortar facing, or surface coat. Ultramarine is an exception to this rule, since a small quantity increases the strength of the mortar, and 30 to 40 per cent may be used without materially decreasing the strength. In fact, ultramarine is one of the best coloring materials, as it does not affect the strength of the cement, provided it is not used in excessive quantities. Germantown lampblack is also good on account of the small quantity necessary to give a good color. Four pounds per cubic yard of sand gives a fairly satisfactory result, although twice as much is frequently recommended for sidewalks. It is unwise to use more than this amount. Other coloring matter should be used in moderate quantities. *Do not use artificial coloring matter in excessive quantities.*

It is a safe plan to try various proportions of color and cement and gauge small parts, and when set and dry select those most suitable for the desired purpose. The color of hardened mortar is quite different in appearance from one that is still wet, so that where it is important to secure the correct tints, preliminary trials must be made until the proportions desired have been determined.

Mixing Colored Facing Mortar.—The coloring material should be measured very carefully so as to get every batch of mortar or concrete of the same shade. Variations in character of cement and sand will affect the result obtained in using coloring matter. Sand for the colored facing mortar must be perfectly dry, and the cement and the coloring matter should be mixed dry before the water is added. With the admixture of coloring matter (pigments), unless extremely thorough mixing is done, there will be a variation in the color of the mortar. The great difficulty, however, is the variation in color between the different batches, due to a slight error in proportioning, the variation in the quality of the coloring matter, or the treatment during setting and hardening. Cement setting in a hot dry place will have a lighter shade than that setting slowly in a cool damp place, even if all other conditions of manufacture are identical. (See page 487.)

The coloring matter is mixed in various ways. In concrete walks it is sometimes sprinkled on the top and troweled into the surface (see page 488). This does not give an even color, nor does it last as well as when thoroughly incorporated with the sand and cement. It is sometimes added to the sand and thoroughly mixed dry, then the cement, and finally the water are added. The best method is to mix the coloring matter with the cement dry, before any sand or water are added. This mixing should be thorough, so that the mixture is uniform in color. In mixing the coloring matter and cement, the greatest care and exactitude are essential. If improperly mixed

the surfaces are apt to be spotty. The mixing is generally done by hand, but better results are obtained by the use of a grinding machine. After this mixing the combination is treated in the same way as clear cement, the sand being added and the whole thoroughly mixed dry; and if broken stone or gravel is to be used it should be incorporated in the mixture dry, the whole mixed until of a uniform color, and water then added gradually, the mixing being continued until the proper consistency is obtained (see Art. 15).

Lampblack is light, dry stuff, and it is difficult to get it thoroughly incorporated with the mortar. Some contractors add it to the cement and mix the two by passing them through a sieve; but the more general practice seems to be to mix the lampblack with the dry sand by turning once or twice, and then to sprinkle the mass and bank it up and allow it to stand at least over night, when the coloring matter will be uniformly distributed throughout the mass. The lampblack and sand can stand any length of time before being mixed with the cement.

In the use of coloring matter it is well to remember that the shade will always be lighter in the cured work than when freshly mixed, so due allowance must be made, when mixing, for this change. In other words, the colors will bleach considerably on drying out. It is therefore advisable to experiment a little to find how much color is needed to give the desired shade. This may be done by preparing sample specimens containing different proportions of the coloring matter and of Portland cement and allowing them to become quite dry before observation.

Directions for using coloring matter may generally be had of the makers. The inspector must carefully follow these printed directions.

Test for Strength of Lampblacks.—Quite often the inspector may be called upon to test the strength of lampblacks to be used. The following simple method may be employed: Weigh out an exact quantity of white lead in oil and an exact quantity of the lampblack which is to be tested. Then mix them together very thoroughly on glass, rubbing them up so as to get a complete mixture. Then do the same thing with the lampblack with which you wish to make the comparison, and by putting them side by side you can see which has the most coloring strength, because the strongest will show the blackest result.

Test for Purity of Lampblacks.—A simple method of testing the purity of lampblacks and detecting not only adulterations but substitutes may be made as follows:

Use only a very small quantity of lampblack, no more than can be lifted on the point of a penknife. A larger quantity will make a less effective test. Put this into a small bottle about two-thirds full of kerosene or benzine, and shake it violently in the hand for two or three minutes. Then hold it up to a strong light and examine it closely. This will show whether it is pure lampblack or adulterated lampblack or one of the numerous rank substitutes made of charcoal, ground coal, etc. If it is pure lampblack it will be diffused completely through the liquid and the particles will be almost invis-

ible because they are so fine and in such perfect suspension. They will remain in suspension without any appreciable settling for two or three hours. If it is adulterated lampblack the color will be less intense and coarse particles can be easily detected in the liquid. These particles will also settle to the bottom in a short time. If it is a substitute the color will be very much poorer still, and it will practically all settle to the bottom very quickly.

Art. 43. Removal of Surface in Various Ways

If made right, the concrete surface will have a skin of neat cement. It is generally desirable for appearance sake to remove this, and there are several ways to do it, depending upon the length of time that the concrete has set, before it can be made accessible for treatment. The time that elapses from the placing of the concrete until the surface can be exposed depends upon the kind of concrete and the nature of the part of the structure in question. If the concrete surface is hard, more vigorous work is required to make it smooth and to take off the skin of cement.

A concrete whose surface has to be removed should be so made that it will have an absorption of not more than 5 per cent by weight.

SCRUBBED OR BRUSHED FINISH

A scrubbed or brushed finish is obtained by removing with a brush the surface film of cement which forms over the aggregate, thus exposing the aggregate to view. This method of treatment gives a rough texture to the surface, and by the use of selected aggregate for the concrete (see Art. 42, page 390) any desired effect can be obtained. The roughness of the surface breaks up the light, the color of the aggregate adds variety and life, and the result is a more artistic surface. In other words, this method of treatment removes the excess cement from the concrete surface, obliterates the marks of the forms and washes considerable of the cement off the surface of the aggregates, so that they appear cleaner, sometimes as clean as freshly-broken stone, and thereby obtain a bright and pleasing effect.

Preparation of Forms.—For scrubbed or brushed surfaces, all that is required of the forms is that the face lagging be kept true to surface and that the joints be tight. When it is proposed to scrub or brush the surface of the concrete before it is more than twenty-four hours old, the forms must be constructed with the idea of being removed without damage to the rest of the structure. For surfaces too large to concrete in one day, the forms should be so constructed as to permit of the removal of sections of the face form. In other words, forms should be built in sections and so arranged that each section can be taken down at the proper time, to give access to the face of the concrete without taking away the standards which provide strength for the forms as a whole. (See Art. 17.)

Placing of Concrete.—Either the small aggregate, viz., sand, or the larger aggregates together with the smaller aggregates, viz., the sand and stone, may be exposed by scrubbing or brushing. There is a

slight difference in the placing of the concrete, depending upon whether the large or small aggregates are to be exposed. Specifications should be explicit as to whether the smaller or larger aggregates are to be exposed by scrubbing or brushing. If they are not, the inspector should learn from the engineer which aggregates are to be exposed, and should see that the contractor clearly understands the requirements. In case the smaller aggregates are to be exposed, the concrete should be carefully spaded between the concrete and the surface in the form (see Art. 41, page 384), as this brings to the surface finish particles of sand and the cement itself. In case the large aggregates are to be exposed, no spading should be done; but all the tamping of the concrete should be done in the middle of the wall, as this causes the pushing of the larger aggregates against the surface of the form.

Great care must be taken in successive casting to prevent marks showing (after scrubbing or brushing) where the new and old work join. In this connection, see Arts. 25 and 26.

Removal of Forms.—For scrubbed or brushed surfaces the forms must be removed from the work as soon as possible, and the concrete surface brushed while still green. Forms should be removed within twenty-four hours of the placing of the concrete during warm, dry weather; otherwise, to remain as much longer as conditions require, which will be determined according to the temperature of the weather, setting quality of the cement, type of work, mixture used, etc. Heavy walls in dry concrete could probably have the forms removed in twelve hours or so after concrete is placed, and the surface could be thus treated. The forms, however, should not be removed so soon on a high section of wall. (See Art. 19.)

Treatment by Scrubbing or Brushing.—The process consists in scrubbing or brushing the concrete surfaces with ordinary fiber (or wire) brushes and water until all of the surface cement has been washed off, leaving the gravel or broken stones exposed and in good relief. If necessary, a small amount of hydrochloric (muriatic) acid should be added to the water. The concrete surface should be scrubbed until the surface film is removed and the aggregate is exposed to a uniform degree, and then rinsed off with water. Water should be freely used from a hose, and the amount of force exerted in the scrubbing or brushing will give shallow or deep cutting effects, as desired. When the forms are removed at the right time, three or four passages of an ordinary scrubbing brush with plenty of water is all that is required. Cement particles removed by the brush must be thoroughly flushed off the surface by clean water, else they will adhere in patches and form blotches.

Brushes for Scrubbing Concrete Surfaces.—For scrubbing the surface, ordinary scrubbing brushes with stiff palmetto or other fiber bristles, with a light stream of water from a hose or can, will generally be sufficient if the concrete has not set too hard. If set is harder, wire brushes followed by fiber brushes and rinsing may be used. Fine and coarse brushes should be used. A cheap and effective brush can be made by clamping or fastening together a

sufficient number of sheets of wire cloth in such a manner as to make a brush about four inches wide. Such a brush will generally be found more effective than the ordinary wire brush for brushing green concrete surfaces.

Precautions to Be Observed.—Care must be taken that the pebbles are not dislodged. The time for scrubbing is when the concrete is still green, but if the concrete is too soft to permit scrubbing, the work must be delayed a sufficient length of time. It is not possible to state how old the work should be before removing the forms and scrubbing the surface. This will depend upon a number of conditions—the character of the work, cement and aggregate used, consistency of the mixture, and very much upon the weather conditions. Care must be taken that the scrubbing is not done too soon, as little particles of aggregate will be removed, resulting in a pitted, unsightly surface. The scrubbing or brushing should be started just as soon as it is possible to do so without removing particles of aggregate. When this can be done can only be determined by experimenting with the particular surface.

The hose should be used without a nozzle, as the pressure may gouge out stones. Water may also be applied with buckets.

Some care must be exercised to make the scrubbing uniform, as too much or too little pressure on the brush will make considerable difference in the appearance of the finished surface. The scrubbers soon get accustomed to this, however, and learn to vary the pressure with the state of hardness of the surface. In scrubbing concrete surfaces, care must always be taken to avoid roughening or blunting corners of the work, and to maintain all edges sharp.

Sand-Blasting.—If for any reason a portion of the surface cannot be or fails to be removed before the concrete has become too hard for removing the surface film by scrubbing, the hard face may be treated by sand-blasting or tool-dressing, to a texture matching the scrubbed portion. (See pages 405 and 403.)

Patching Defective Work.—If any void spaces appear, or if spalls are broken off, the defects should be patched with similar mix immediately after the scrubbing, using the hand or a wooden float—not a steel trowel—for applying and smoothing the patches. After they are sufficiently set (say, within 5 to 24 hours) all patches should be scrubbed to the same texture as the general surface and be rinsed clean and kept moist for several days. In this connection, see Art. 30, page 338, and also page 365.

Pebble-Dash Facing.—The concrete should be composed of gravel and rounded stone not exceeding 1 in. in its smallest diameter. When the forms are removed the cement and sand must be brushed from around the face of the gravel with fiber or steel brushes, as described above, leaving approximately half of the gravel exposed. Brushing should commence within 24 hours after the concrete has set.

Instead of exposing the pebbles in the aggregate proper, the following method of artificially exposing aggregate may be employed: After erecting the forms of rough boards in the usual manner, in courses of 3 ft. or less, plaster inside of these forms with wet clay,

and to this wet clay apply different colored pebbles in sizes of 1 in. down to those that will be retained on a ¼-in. screen. The pebbles will thus stick to the clay. Concrete may now be poured in and the forms removed in the usual time. The clay is to be washed off with a hose and the concrete surface scrubbed slightly with a brush. Care must be taken that the pebbles are not dislodged. Any colored pebbles desired may be used in this way, and the pebbles will give some very delightful and varied effects. In this connection, see Art. 42, page 390.

Other methods of securing pebble-dash finishes are discussed in Art. 44, page 414.

Cut-Stone Facing.—A method similar to the one used in obtaining a "pebble-dash" may be employed in giving to concrete the appearance of cut stone. In this case crushed rock is substituted for the gravel, the character of the rock depending upon the color and texture desired in the finish. After the removal of the forms the cement and sand must be brushed from around the face of the stone next the face exposed to view, followed by clean water. (See page 415.)

RUBBED FINISH

It has been found that it is not always practicable to remove the forms so soon; hence, the concrete sets up hard, and the scrubbing or brushing, as mentioned above, has little effect on it. To meet this objection the concrete may be rubbed with a soft brick or block of concrete. These are rubbed with a circular motion. The process of rubbing consists in grinding down the surface of the concrete sufficiently to remove all impressions of the timber or other irregularities, and where but little coarse aggregate is used, or where the aggregate has been spaded back from the forms as referred to in a previous paragraph.

Preliminary Preparations.—In no case on an exposed surface of the concrete should joints of any component pieces of the forms, nor the grain of the wood, be visible. Some preliminary treatment will therefore be found necessary, such as clipping off rough projections, as those left by cracks in the form, filing off the arrises, etc. Noticeable voids, or stone pockets, should be filled with mortar in the same proportions as the mortar in the concrete. For methods of patching and repairing defective concrete surfaces, see Art. 30, page 338.

Treatment by Rubbing.—The method of procedure consists in thoroughly wetting the concrete after the forms are removed, and then rubbing with a circular motion the wet surface with a coarse carborundum stone (No. 16), bringing the surface to a lather. After this stone has been used sufficiently to take off the rough projections and irregularities, the lather must be washed off with a brush, and the surface again wet, and then dusted with a mixture of dry sand and cement, the proportion being 1 part Portland cement and 2 parts dry sand. This coating must be well rubbed into the surface with the coarse carborundum stone (No. 16). Care must be taken not to allow any of the mortar to remain on the surface. To give

the final finish, a No. 30 carborundum stone should be used and the whole surface well rubbed.

Best results may be obtained where the concrete has not set hard, preferably a day or two old. A vigorous use of water is also advisable. In the absence of carborundum stone, a block of hard wood, sandstone, old concrete, emery, or pieces of white fire brick or briquettes of one cement to one sand, made in molds about the size of a building brick, handles being pressed in while soft, may be used. By dusting on a thin coating of cement and sand in the proportions stated above, gives a lighter surface than troweling, fills any voids that may be in the surface, and leaves the concrete more waterproof than it would be ordinarily.

A cement wash may be substituted for the dry sand and cement, being composed of 1 part Portland cement to 2 parts of fine sand. This wash should be applied immediately after the concrete surface has been thoroughly rubbed with a piece of sandstone or carborundum stone, and the surface rubbed with a No. 16 carborundum stone and the work afterwards washed down with clean water. The grout should be used simply to fill surface imperfections, and must not remain as a film on the surface (see page 406). The result, after the setting of the grout, is a very smooth surface. In hot weather it should be frequently dampened for several days to prevent the small surface cracks so often seen in a finish of this kind.

Precautions to Be Observed.—In rubbing concrete surfaces care must always be taken to avoid roughening or blunting corners of the work and to maintain all edges sharp. Plenty of water should be used, either by dipping the sandstone or other rubbing block into the water or by throwing the water on the wall with a whitewash brush or small broom. (See also page 399.)

ACID WASH FINISH

Applying dilute hydrochloric and sulphuric acid to concrete surfaces consists of another type of the scrubbing or brushing process (see page 397), being employed for the purpose of removing the outer skin of cement and exposing the aggregate. A desirable surface, however, may be obtained by simply brushing and washing with a hose and clean water, but the final acid treatment in connection with brushing and washing produces a still better finish, as the acid thoroughly cleans the surface of the aggregate, thereby intensifying the color and texture of same. This process is generally applied in cases where the surface has hardened to such an extent that brushing alone involves too great an item of work.

An acid wash finish is applicable to all types of concrete work, and when the cement has been properly dissolved away from the particles of aggregate the various shades of browns and reds of gravel may be very pleasingly brought out. It has been applied with equal success to troweled surfaces, like pavements, to molded forms, such as steps, balusters, coping, flower vases, etc., and to concrete placed in forms in the usual way. The treated surface can

be made of any desired color by selection of colored aggregates (see page 390) or by the addition of mineral pigments (see page 391).

The disadvantages connected with this method are the high cost and the difficulty of handling the acid to apply it and the fact that the acid wastes and if not neutralized may penetrate into the base of the structure and destroy the concrete.

Preliminary Preparations.—The concrete work should be deposited in a fairly dry mixture and care taken not to use materials which are disintegrated or affected by either sulphuric, hydrochloric or acetic acid. Sand and crushed granite give good results, but limestone generally disintegrates under the action of the acid. In other words, only such materials should be used as will not be affected by acid. Some preliminary treatment will generally be found necessary, such as chipping off rough projections, as those left by cracks in the forms, filling off the arrises, etc. Noticeable voids, or stone pockets, should be filled with mortar in the same proportions as the mortar in the concrete. For methods of patching and repairing defective concrete surfaces, see Art. 30, page 338.

Treatment by Etching.—The method of procedure consists in thoroughly scrubbing or brushing the concrete after the forms are removed, as described on page 398, for the scrubbed or brushed finish, and then washing with a diluted solution of acid applied with a brush. The acid may be applied with an ordinary calcimining brush. While wet with acid the surface must be quickly worked over with an ordinary scrubbing brush and the acid immediately removed with clean water applied through a hose in sufficient volume to cleanse and flush the surface thoroughly. After the scrubbing is completed great care must be used to remove all traces of acid, otherwise the acid will continue to etch out the cement in places and give a permanent discoloration of the surface, causing it to have a mottled, streaky appearance. The acid should not be allowed to remain on the surface for any length of time—not over half an hour—and must be thoroughly washed off with a hose and clean water. Any remaining traces of acid may be detected by tasting the water left on the surface. Hydrochloric acid is preferable.

The operation of applying acid to concrete surfaces is simple and always effective. It can be done at any time after the forms have been removed, immediately or within a month or more. It requires no skilled labor—only good judgment as to how far the acid or etching process should be carried.

Amount of Dilution Necessary.—The amount of dilution for hydrochloric and sulphuric acid should be determined by experiment, as it varies with the age of the concrete. The older the concrete, the stronger should the solution be. For concrete which is about two weeks old, ordinary commercial acid may be diluted with three parts of water. When but a few days old a dilution of one part acid to five or six parts of water should be used. A mixture of the two acids will produce a stronger action than the use of one alone.

A solution of one part commercial muriatic acid to two or three parts of clean water should generally be used on surfaces in which

standard Portland cement is used, and a sulphuric acid solution of the same strength when white Portland cement and white aggregates are used in the facing mixture (see pages 391 and 488).

Rewashing Surfaces Composed of Selected Aggregates with Acid.—Should the surface become stained after being scrubbed and washed by placing course upon course as the wall is erected, the wall should be washed off with water played on the surface by means of a hose each night as the day's work is completed, and after the wall is completed to the top the whole surface should be gone over with one part commercial muriatic acid and four to six parts water, the solution of muriatic acid being applied with an ordinary whitewash brush, having very little exposed metal. The acid should be left on the walls from fifteen to thirty minutes, after which it must be washed off with a hose, and in places where the stains are most noticeable the surfaces should be scrubbed with an ordinary scrubbing brush.

Removal of Efflorescence.—Efflorescence, a white or a yellow deposit on the surface of concrete, may be removed by using a weak solution of hydrochloric (muriatic) acid, one part of acid to six or ten parts of water. The wash should be well rubbed into the pores of the concrete with a brush and then rinsed off with clean water as soon as the efflorescence has disappeared. Efflorescence may also be removed by the application of soap and alum washes on the surface (see page 437). For other methods of removing efflorescence, see Art. 31, page 346.

TOOLED FINISH

Concrete surfaces are sometimes bush-hammered or otherwise tool-finished in a manner similar to that used in treating natural stone. This chips off the mortar which may have flushed to the surface, cuts away little particles of the mortar from the aggregate below. The roughening of the surface breaks up the light, gives a lighter color to the mortar itself, and, besides this, exposes the color of the aggregate below. A variety of textures of surface may be obtained by tooling with pneumatic tools or by hand. In other words, fine picking, chiseling or hammering, either by pneumatic tools or by hand, will produce differing effects, according to circumstances. This additional color on the concrete adds a great deal to its appearance. The dressing also removes most of the traces of the form and does away with irregularities which may occur in the work.

While the result may be effective, tooling concrete surfaces is rather expensive and slow work, and is but sparingly used. Another objection in tooling concrete surfaces comes in the removal of the surface mortar, which is the most waterproof part of the concrete. If there is any tendency toward porosity in the mass of the concrete it will absorb more moisture after tooling than before it, and will accentuate the injury from frost. On well made and properly proportioned concrete there is, however, very little if any danger from this, as the material is of itself very dense and water-tight.

This method of finishing the surface cannot ordinarily be applied

to gravel concrete, as the pebbles will be dislodged before being chipped.

Preliminary Preparations (Forms, Etc.).—Contrary to the practice most favorable for a scrubbed or brushed finish (see page 397), the concrete must be well hardened before tooling. This does away with the need of building form work so that it may be removed in sections, as is necessary in scrubbed or brushed work. Where it is decided beforehand to tool the work, less pains need be taken in dressing the lagging of the forms. Care must be taken, however, with the forms, for unless form lumber which is uniform in thickness is employed it becomes necessary to tool some parts of the surface deeper than others. Forms may be constructed of rough lumber, if more convenient, and the form marks and blemishes on the concrete surface removed by careful tooling. (See Arts. 16 and 17.)

When the concrete is to be tooled, from 30 to 60 days should elapse before the concrete is hard enough, especially where distinct edges and sharp, clean surfaces are desired. To secure good results, the concrete must be at least 30 days old before it is worked.

The size of stone in the concrete should be limited to about 3/4 to 1 inch. Small-size aggregate will give the best results, owing to the absence of large pieces of hard material in the concrete.

Treatment by Tooling.—A dressed finish may be obtained by dressing the concrete surface with a pointed or toothed hammer, usually with a small stone pick, to represent natural stone. This must be done after the concrete has thoroughly set. The tool should be light, and the blows only heavy enough to "scalp" the work, heavy tools and blows being liable to "stun" the concrete, particularly at or near the edges. This scalping partially exposes the material of the aggregate, but does not clean it. The complete exposure and cleansing will come with time and exposure to the weather, if the work be outdoors; or the action of the elements can be anticipated by washing the tooled surface with hydrochloric (muriatic) acid diluted about one-half, which must be thoroughly washed off (see page 402). (See also pages 336 and 365.)

A little variety to the texture can be obtained by the method in which the blow in picking is applied. By striking a perpendicular blow there is no resulting mark left on the concrete surface by the tool, whereas with a glancing blow lines are left, and these can be made to show all parallel to one another or at various angles, and thus somewhat of a variety to the texture may be obtained.

Bush-hammering is the most popular method used for dressing concrete surfaces by tooling, while other forms of finish have been employed with satisfactory results. It may be used for fine detail work, finished concrete block, and for imitations of natural stones, and may be done either by hand or with a pneumatic (or compressed air) tool. In hand-hammering, the concrete should be allowed to stand at least three weeks after placing, preferably longer. The concrete must not be too green, or the hammer will loosen the stones and thus spot the surface with objectionable blemishes, and possibly

opening up some internal cavities and starting a leak in the wall. On the other hand, the concrete should not be allowed to stand too long, for the labor will be unnecessarily great. Three months is about the limit, for concrete becomes practically as hard as the stone going to form the larger aggregate, and hand-hammering has very little or no effect whatever upon the concrete.

Another method of tooling consists in removing the skin forming on concrete surfaces with a coarse-grained emery or carborundum wheel. The skin is cut about as quickly as the block can well be passed over the wheel. This method is well adapted to the surfacing of molded blocks, slabs, and artificial stone. (See also page 515.)

Tools for Dressing Concrete Surfaces.—Tooling may be done with an axe, pick, chisel, hand or pneumatic hammer. Various weights and sizes of tools have been used. Preference should be given to a tool light in weight and having but few points.

Precautions to Be Observed.—In tool-dressing, care must always be taken to avoid roughening or blunting corners of the work, and to maintain all edges sharp. The concrete must not be too green, or the pick will loosen the stones.

SAND-BLAST FINISH

The exposed aggregate effect can also be obtained by what is known as the sand-blast finish. The operation of impinging sand by means of compressed air against the surface of the concrete produces a finish similar to that produced by scrubbing or brushing green concrete, as described on page 397. It removes the plastic or pasty effect given to the concrete by the forms and produces a granulated finish, somewhat similar to sandstone, but not so uniform, because the aggregates are likely to be brought out irregularly. This method leaves the stone cleaner than with scrubbing and acid treatments. (See pages 347 and 515.)

Sand-blasting is very effective and, if carefully done by an expert, can be made to produce panels, belts, etc., and the effect of the blast can be carried as deeply as desired. It has been successfully employed in a number of important structures. Sand-blasting, however, is not likely to be a success unless it is done by experienced workmen.

Preliminary Preparations (Forms, Etc.).—It is not necessary to construct the forms so they may be taken down in sections, as required for scrubbed or brushed surfaces, for the concrete should be thoroughly hardened before sand-blasting, especially if sharp edges and surfaces of a fine, uniform texture are desired.

Any pronounced ridges or irregularities in surface formed by cracks or open joints in the forms should be removed by tooling, and any pointing that may be necessary should be done several days before the surface is sand-blasted. (See Art. 30, page 338.)

Samples of Sand-Blasting.—Samples of sand-blasting should be submitted to the engineer for his approval before any sand-blasting is commenced. These samples should be submitted for inspection as early as possible.

Treatment by Sand-Blasting.—The operation of the sand-blast consists in forcing a stream of thoroughly dried silica sand, or crushed quartz, through a small nozzle by means of air pressure at 50 to 75 lbs. per square inch at the nozzle. The nozzle should not be over $\frac{1}{4}$ in. in diameter and must be held within a few inches of the surface to be cut. By a slight cutting of the surface the appearance of sandstone is obtained. Deeper cutting will remove more of the mortar which has been flushed against the forms, and the aggregate will be exposed.

Sand-Blasting, Molding, Joints and Courses.—Strips nailed to the forms to make moldings, joints and courses should be left in place while the surface is being sand-blasted. Otherwise, the sharp angles and edges will be rounded off in a rough and unsightly manner. The area protected by the strips should be left unfinished, unless otherwise desired.

Size of Nozzle.—It is important to have the right size of a nozzle for sand-blasting. A $\frac{1}{2}$-in. diameter nozzle would produce very unsatisfactory results, because if an excess of cement came to the surface at one spot or on an edge as a joint between boards, its hardness would resist the cutting of the sand, while softer portions on either side would be removed, thus emphasizing the ridge. Similarly, a soft spot formed by a wide crack where the cement all ran out, leaving the sand behind, would be cut deeper by a large nozzle. The nozzle should not be over $\frac{1}{4}$ in. in diameter, preferably not over $\frac{1}{8}$ in. in diameter, so that it can be localized on small spots.

Material for Sand-Blasting.—A clean, coarse, thoroughly dried silica sand or crushed quartz should be used for sand-blasting, and for use with a $\frac{1}{4}$-in. nozzle the sand should be screened through a No. 8 screen, and through a No. 12 when a $\frac{1}{8}$-in. nozzle is used.

Precautions to Be Observed.—In sand-blasting, care must always be taken to avoid roughening or blunting corners of the work, and to maintain all edges sharp. The concrete must not be too green, or the sand-blasting will loosen the stones. Good results can be obtained when the concrete is between 10 and 14 days old.

Art. 44. Coating Surfaces in Various Ways

GROUT WASHES OR FINISH

A washed or grout finish may be obtained by finishing the concrete surface with a thin mortar grout rubbed into the concrete with a float and then brushed over with a wet brush, or rubbing the entire surface down with cement bricks, or sometimes hardwood blocks (see page 400). If a non-staining cement is used for this purpose a very good appearance can be effected which will look uniform.

The chief objection to grout coatings is that they have a tendency to peel or crase. If the purpose is to fill the pores of the concrete surface only, there can be no criticism of this method, provided all the surplus grout is again removed; often the grout is allowed to remain on the surface as a thin film, in which case more or less peeling

is bound to follow. Many arches, abutments and retaining walls throughout the country have been provided with a coat of grout, and there is hardly any locality where samples of this work may not be found showing the disgraceful results obtained. Grout finishes should serve only to fill the small pits and pores in the surface coating, and not be put on as a plaster.

Preparation of Surfaces.—All exposed surfaces must present a smooth, uniform surface of cement mortar, the concrete being spaded, for only by thorough spading can air bubbles be worked out. The stones must be spaded away from the face carefully but judiciously; too much and unskillful spading will permit an upward flow which will wash the cement from the concrete at the face. Forks, spades or other suitable instruments should be used for this purpose, being small enough to be pushed along all faces of the walls. In this connection, see Art. 41.

After the forms are removed, all disfigurements must be effaced, and if there are any open, porous places they must be neatly filled with a 1:2 or 1:3 mortar before applying the wash (see Art. 30). Any ridges due to cracks or joints in the forms should be rubbed down smooth and hard with a float, and the rubbing continued until the marks of the forms are entirely effaced. In other words, cavities or joint lines, if any exist, should be removed by plastering or rubbing before the grout is applied, or else by applying the grout by rubbing.

Treatment of Surfaces with Grout Washes.—A washed or grout finish may be obtained by removing the forms within ten or twelve hours after the concrete has been deposited, under ordinary temperature, and finishing with a thin mortar grout, well rubbed into the concrete with either a wooden float or a piece of sacking, and then brushing over with a wet plasterer's brush. The walls should be wetted with water before applying the wash.

The grout may be mixed in the proportions of one part Portland cement to one or two parts of coarse sand, and should have the consistency of whitewash. A good mixture is one of Portland cement to two of sand mixed thin enough to be applied with a whitewash brush.

The grout may be applied in any manner, provided a uniform appearance is produced without leaving a scale on the work. A compressed air machine may be used where there is a large amount of grouting of surfaces to be done. In ordinary work the grout is generally applied with a brush. If applied with a brush the grout should be about the consistency of whitewash. Instead of a liquid grout a stiff grout or semi-liquid mortar is sometimes applied. If applied with a trowel or float, the grout should be stiff and applied in a very thin coat and troweled or rubbed so that only the pores are filled and no body of the mortar left on the surface. The grout coating may also be applied to a thoroughly wet surface by throwing with considerable force by means of an ordinary whiskbroom.

Grout coating or washes should be kept damp for at least a week by hanging dampened sheets of burlap close to the surface.

Coloring Grout Washes.—The color of the finished surface will be considerably lighter if plaster of Paris is substituted for about one-quarter of the cement.

Where a dark finish is desired, a grout may be made by mixing neat cement and lampblack in equal parts, applying two coats with a brush, the second coat after the first has dried, and one coat by sweeping with a small whiskbroom.

One pound red iron ore to ten pounds cement, mixed dry and then made into a thin grout and applied to a well-cleaned concrete surface with a whitewash brush, gives a brick-red color; a rich dark red is given by one pound red iron ore to three pounds of cement. The sooner this is applied after the concrete has set, the more likely is it to remain permanent. (See also Art. 42, page 394.)

Plaster of Paris Wash.—A very pleasing finish may be given by applying to the set concrete a thin wash composed of equal parts of Portland cement and plaster of Paris, though the permanence of such a wash may be open to question. The concrete surface should be cleaned from any oil or grease that may have come from the forms, and the wash applied with a whitewash brush. This mixture gives a very light gray finish, and where a trifle darker shade is desired, one part of plaster of Paris to three parts of Portland cement may be used.

Cement-Milk Paint.—Stir into a gallon of skim-milk about four pounds of Portland cement. The skim-milk will hold the paint in suspension, but the cement, being heavy, will sink to the bottom, so that it is necessary to keep the mixture well stirred with a paddle while using. Mix only enough at a time for one day's use. This paint becomes hard in about eight or ten hours, and is very durable. It can be colored by using any of the pigments mentioned on page 392. The addition of carbolic acid or any other disinfectant makes it very suitable for dairy work, chicken houses, and the like.

Precautions to Be Observed.—Grout finishes should serve only to fill the small pits and pores in the surface coating. Care must therefore be taken to see that the workmen do not get a coat of the grout on similar to a skim coat of plaster, as that will generally peel in cold weather.

WHITEWASH FINISH

Sometimes it is desired simply to whitewash a concrete surface to secure a uniform color, though the permanence of such a wash is very questionable. Whitewash, however, when made right and properly applied, gives a coating that resists wear well and that retains its brilliancy for years.

Preparation of Surfaces.—Concrete surfaces to be whitewashed should be prepared in the same manner as that for grout washes described above. (See pages 407 and 448.)

Whitewash Finish.—The following formula for a whitewash finish has been taken from Prof. Ira O. Baker's "Masonry Construction," page 179, edition of 1909:

"Slake with warm water half a bushel of lime, covering it during the process to keep in the steam, and strain the liquid through a fine sieve or strainer. To the slaked lime add the following: 1 peck of salt previously well dissolved in warm water, 3 pounds of ground rice boiled to a thin paste and stirred in boiling hot water, ½ pound of powdered Spanish whiting, 1 pound of glue which has been previously dissolved over a slow fire, and 5 gallons of hot water. Stir well and let the mixture stand for a few days, covered from dirt. Strain carefully and apply hot with a brush or a spray pump. Coloring matter (see page 392) may be put in to make almost any desired shade."

PAINTED FINISH

Tinting or coloring of concrete surfaces may be obtained by the use of special coatings prepared for the market. It is not satisfactory to use ordinary paint on a concrete surface. Special preparations give much more lasting and satisfactory service. There are on the market, sold under various proprietary trade names, a multitude of special paints and finishes for concrete surfaces, giving a wide range of color effects and also serving more or less efficiently the purpose of weather-proofing and dampproofing. The ordinary paints, especially of the cold-water variety, are usually not very satisfactory.

Enamel paints may be used. Care must be taken, however, that no water or frost is allowed to get behind the enamel, otherwise it will cause the enamel to peel off. Enamels should not be baked upon a surface, because the process of baking has a tendency to dehydrate the cement and cause the mortar to crumble.

Preparation of Surfaces for Painting.—Concrete surfaces should be free from oil, grease or other foreign matter, and thoroughly cleaned and dried before painting. Oil paint will not stick to damp concrete nor to perfectly dry concrete except under special conditions, as the alkali of the concrete and the oil of the paint unite to form a soft, sticky substance similar chemically to soft soap (see page 440). No surface is free from dirt and foreign matter, and it requires the removal of such substances, either by wire-brushing or acid treatment, to secure a firm bond and penetrating quality to the surface.

In other words, in painting concrete surfaces the material employed should either be neutral, free from saponifying oil, or the surface to be painted should be previously neutralized with dilute sulphuric acid in order to convert the free lime into gypsum. If such precaution be neglected the oil and free lime will generally react chemically and form soap which will destroy the paint. No acids, however, should be used unless properly neutralized and washed off with water and the surface allowed to dry out thoroughly. Generally no surface treatment or reagent is necessary after proper aging of the concrete surface—six months to a year.

Concrete surfaces may be treated with a solution of zinc sulphate and water, mixed equal parts by weight, and applied with an ordinary

bristle brush after the concrete is dry. The concrete should be at least 48 hours old, preferably 72 hours, before applying the zinc sulphate solution.

Concrete surfaces to receive oil paints may also be thoroughly washed with 7 to 8 per cent solution of muriatic acid and followed by a good wash of clean water (see pages 328 and 402).

Application of Paint to the Surface.—After the treated surface has thoroughly dried, the paint may be applied, using enough turpentine in the priming coat to make it almost flat, and increasing the amount of oil each succeeding coat.

Printed Directions to Be Followed.—Where special preparations are used in painting concrete surfaces, care must be taken to follow closely the directions of the manufacturer of the preparation. When these paints are used the inspector must follow the printed directions for applying each.

Spraying Machines.—Compressed air spraying machines may be used for applying cold water paints to concrete surfaces. Care must be taken that the paint is applied uniformly.

PLASTERED FINISH

Plastering as a method of finishing concrete surfaces should not be employed, especially on outside work, as it is practically impossible to apply mortar in thin layers and make it adhere for any length of time, due to differences in expansion of the materials of different composition and age. It should be used for indoor work only, and then only in emergencies. Scaling of the plaster coat is particularly noticeable in the case of walls above ground, which are subject to varying degrees of temperature. A plaster coat, however, is sometimes applied to a concrete wall to make it waterproof, as described in Art. 49, page 442. (See also page 460.)

The reason that plastered work breaks off is that the mortar in setting up shrinks. The richer it is the more it shrinks, and the shrinkage results in leaving a hair plane between the plaster and the concrete work. The frost does the rest.

A great many so-called concrete workers and concrete contractors do not attempt to cast fine arrises, but assume from the start that they will fix up the work by plastering after the forms are removed. Occasionally the details will not turn out as well as they should, and under such circumstances a thin veneer of mortar is permissible, but should only be applied by an expert concrete finisher.

Where it is necessary to cast a cornice in place, the top surface of which is comparatively flat, it is impossible to get an even finish against a top form. Leave the top form off, tamp carefully to grade, and as soon as the concrete has a fairly good set, from 4 to 10 hrs., rub it down to an even grade with a small flat stone or a wooden float (see page 400). It ought not to be necessary to add any additional mortar to make this finish. However, if there is a poor job on this part of the work and it is necessary to rub it up, using additional mortar, roughen it slightly with a mason's axe, wet it thoroughly

and rub on a coat of not more than ⅛-in., using about a 1:3 cement mortar which has been set up three or four hours.

The treatment of concrete surfaces by exposing the aggregates, as described in Art. 43, will generally be found the cheaper and better method of securing a more pleasing surface than by plastering or by the use of a full, smooth mortar surface, the mortar being a part of the body of the concrete, with the stone in the concrete worked back so as not to be exposed, as described in Art. 41, page 385.

There are various plasters on the market, made especially for concrete surfaces. A great deal of satisfactory work has been done with such material, but its general use is still too recent to warrant absolute confidence. It is much safer to avoid plastering. It is, of course, advisable to fill with mortar any voids that may appear in the face of the work, but such places should be few and far apart (see Art. 30, page 338).

Tile-concrete construction is well adapted for plastering (see page 313).

Preparation of Surface.—In case a plaster finish is called for, the concrete surface to be plastered must be specially treated to receive the plaster coat, depending upon whether the wall is new or old. In that case, very fair results may be obtained, but plastering always remains an art more than a science, so that skilled labor is a most essential feature. It cannot be too strongly insisted that proper precautions be taken to make the plaster stick.

The best results are obtained by placing the plaster immediately after the forms have been removed and while the concrete is still green, rough timber being used for forms and no care exercised to see that the surface as left by their removal is at all smooth. In this case, very little or no preparation of the concrete surface is necessary to receive the plaster, which is applied before the wall has dried out. It may be wise in some cases to cast dovetailed recesses in the mass work.

If the concrete wall is old, much care must be taken in preparing it for the plaster. In many cases it is well to wash or scrub the surface, or to pick it to make it rough, before applying the plaster. The surface should generally be quite rough, thus making a surface with a good suction, as painters term the property that makes a surface eat up paint, so as to form a clinch for the plaster. The excess of cement likely to have flushed to the surface must be removed, being first gone over with a wire brush, followed with a weak acid, such as strong vinegar, sour beer, a weak solution of hydrochloric acid, etc. (see page 328). The surface should then be gone over several times with a wide brush dipped in water until all traces of the acid have been removed. The surface must be thoroughly cleaned and then wetted just before applying the plaster, or it will crack and fall off. (See pages 339 and 448.)

Instead of applying the plaster finish directly to the concrete surface, the method of using a lath to support the plaster may be employed, as described in the next paragraph.

Metal Lath and Furring.—The metal lath must be of sufficient

rigidity to readily take mortar when supported by furring spaced about 16 in., center to center. The lath is generally wired to the furring angles or channels every 8 in. with No. 18 annealed galvanized steel wire, care being taken to have sufficient lap in the lathing. The lath should be tied together and also to the furring, so that there can be no settlement or sagging of the lath or the furring to which the lath is attached. Galvanized metal lath should be used for outdoor purposes. There are various kinds, woven, welded, expanded, any one of which can be used. That having a large cross-section of metal and being heavily coated with galvanizing material is likely to be the most durable, if moisture should penetrate through the plastering to this material.

The furring should have sufficient space for the mortar to push through the mesh and clinch without interference from the backing to which the furring is attached. Furring and laths should leave an air space of at least ¾ in. for exterior walls. It must be protected from rusting by being entirely galvanized or treated by any other equally efficient process.

Use of Nails as Furring.—At frequent intervals wire nails may be driven in the forms on the inside, so that the pointed ends project about 2 in. outside of the rough concrete after the forms have been removed. Before applying the plaster a small iron nut may be put on each projecting nail; the concrete work being then covered with a wire lath of 2½ meshes to the inch and No. 20 wire, and the nails bent over it with the blow of a hammer. The nuts will serve to keep the wire lath a distance of about ¼ in. from the old concrete surface. The nails should be about 3 in. long, with a bend of ¾ in. at one end. The nuts may be either square or hexagonal, about ¼ in. high.

Metal Lath and Wooden Furring.—Concrete walls may be provided with 1¼x3-in. thoroughly dried and seasoned furring strips about 18 in. apart, to which may be fastened substantial metal lath and this plastered with lime mortar.

Proportioning, Mixing and Placing Plaster.—Do not use a rich mixture for the plaster. A lean mixture gives far better results than a rich mixture and is not so liable to show hair cracks. Quick setting causes hair cracks and a rich mixture sets quickly. One part of Portland cement to three parts of clean, coarse sand should generally be used.

Lime paste added to the mortar is advisable in some cases, especially for concrete building walls. This increases the adhesion and lessens the liability of cracking. If a hard surface is desired, only a small amount of the paste should be used. The mixing must be thoroughly done. The lime mortar should be mixed at least five days before using, and the cement should not be added until the mortar is ready to be used, and should be mixed in small quantities as the work progresses. The lime should be completely slaked, as trouble will surely result if it is not.

The first, or scratch, coat may be composed of one part Portland cement, three parts sand, and one-half part hair putty. This hair

putty should consist of long cattle hair or fiber, thoroughly worked into good lime putty. Before coating the surface the base should be thoroughly saturated with water so as to avoid suction of moisture from the covering coat, which would impair its strength and durability. Care must be taken to apply the plaster at once in a thin layer and scratch it before the surface has an opportunity to dry. Apply with a hard pressure and let it set until strong enough to carry the next coat. By throwing on plaster with considerable force it bonds better than by spreading it. If the first coat is thrown on, the second is more apt to adhere. The face of the first coat must be well scratched to make a key for the second coat, and should be thoroughly dry and surface cracks appear before the second coat is applied.

The second coat may be composed of one part Portland cement, two and one-half parts of sand, and with not over 5 per cent lime putty and the cow-hair omitted. Before applying the next coat, wet the scratch coat and then apply the second coat in the same way. Before the second coat has set hard it may be jointed to present the appearance of stone work.

The third or finishing coat may consist of one part of Portland cement to two and one-half parts of sand or screenings, with not more than 5 per cent of lime putty. (Crushed marble screenings may be used for the facing mortar, unless otherwise desired, or mineral coloring matter may be used [see Art. 42].) To this finishing coat may be added pebbles or other non-combustible material as may be desired to obtain a variation in the finished appearance. Screenings or sand must not be too fine, but should be from ¼ in. diameter down (see Art. 8). If desired, the last coat may be thrown on in order to produce a rough surface. Three coats will generally be sufficient. The surface effect is obtained by using different kinds of finishing tools.

In all cases, one coat must follow the previous one as soon as it has sufficiently set to allow of so doing. There should be no difficulty in causing the layers to adhere to each other, if properly applied. The concrete should be well sprinkled before the plaster is laid, as the interior concrete, being dry, will otherwise absorb moisture and prevent adhesion. Avoid as much as possible the working of material more than merely enough to make it adhere.

Where a total thickness of not more than 1 in. is required it is practicable to apply it in two coats; i. e., omitting the second coat above specified.

Joints should be allowed at intervals and made as inconspicuous as possible. Plaster should never be applied when the temperature is below freezing.

The finished surface should be protected for at least two weeks with canvas curtains or bagging saturated with water. (See page 445.)

Thickness of Plaster Coat.—A plaster coat should either be very thin—that is, just enough to fill irregularities (as described for grout washes on page 406)—or it should be from 1 to 3 in. thick, so that it will have some strength in itself. (See page 303.)

Smooth Float Finish.—Such finish can be obtained with a wooden float. Floats should be made of hard, close-grained timber, such as beech or birch, and should be drawn straight along the wall, without twisting or turning. Smoother finishes can be obtained by the use of steel trowels or with wooden floats covered with felt. Troweling brings the neat cement to the surface, while the float tends to bring out the grains of sand. A metal trowel is seldom employed, as fine cracks are more apt to become visible. For precautions to be observed in using steel trowels, see page 484.

Rough Finish.—A heavy sponge tapped lightly on the fresh mortar gives a rougher finish much used, while in other kinds of work different effects are secured by throwing on the material with a stiff brush or trowel.

Splatter-Dash or Slap-Dash Finish.—An inexpensive manner of plastering is what is called a splatter-dash or slap-dash coat. It can be obtained by throwing the finishing coat into the first or second coat, as the case may be, with a broom made of twigs, dipped into a solution of mortar, half and half, or two of sand to one of cement, and applied by stepping back a distance of two or three feet from the wall and striking the broom with the hand in such a way as to drive the mortar against the wall, on which it collects like raindrops. The mortar may also be applied by throwing it from a trowel, standing two or three feet away. Not all of the mortar will stick at the first attempt, but enough will adhere to form a bond for the next application, and so on. The process should be continued until an even surface is produced. The cement crystallizes and adheres firmly to the wall. It is possible to mark off the plastic surface into oblong forms or into geometric designs. A rough surface is generally better in appearance and less liable to crack than a smooth surface. By the use of white mortar a sparkling, glistering effect is obtained (see pages 391 and 488).

For the successful application of a splatter-dash or slap-dash finish, the workmen must possess considerable skill. In fact, it takes an expert to do good work. The scratch-coat to which the finish is attached should not have attained too great a set to prevent bond.

Pebble-Dash Finish.—A pebble-dash finish may be made by throwing on mortar and leaving it rough. The cement and lime paste should be mixed to the consistency of thick cream and washed pebbles added in the proportion of five parts plaster to one part pebbles, by volume.

Pebble-Dash Finish (Alternate Method).—A pebble-dash surface may also be obtained by applying the finishing coat of plaster fairly wet and throwing clean pebbles into the fresh plaster. Excellent effects are obtained with white quartz pebbles, and warm effects with colored stones or gravel (see page 390). The pebbles should be about ½ in. in diameter and should run uniformly.

The pebbles must be wet just before throwing them on the fresh plaster. The work should be started at the top and the pebbles thrown with a sweeping motion such as is used in sowing seed. The pebbles must be distributed uniformly over the surface and must be

thrown with sufficient force to embed them securely. Care must be taken not to disturb the cement after it has started to set, and in order to avoid this the surface must be covered with the pebbles immediately after the fresh plaster is applied. Particular care must also be taken to make the whole surface continuous; that is, one patch of plaster must not be allowed to dry before the adjoining space is covered.

This is a simple and inexpensive yet thoroughly practical method of securing an artistic effect. Sometimes large pebbles are employed and each individual stone placed where it is desired it should be.

Art. 45. Other Methods of Exterior Finish

Cut-Stone Finish.—Strips of wood can be nailed into the forms to give the effect of cut stone to concrete surfaces when the forms are removed. These grooves are supposed to represent joints in the stone that the concrete is intended to imitate. The better practice, however, is not to try to make concrete imitate any other material. The reason is obvious. (See page 400.)

Clapboard Finish.—Exterior forms may be arranged by letting the outside boards 1 in. thick lap over each other, the exposed width being about 10 in., to give the effect of clapboard finish. The concrete may be left as it comes from the forms, no rubbing whatever being required.

Panel Finish.—A broad surface may be relieved of its monotony by paneling. The larger and rougher the surface, the bolder the panels should be. Long retaining walls should preferably have panels to relieve the dead flat surface.

Inserted Patterns (Colored Clay, Tile, Etc.).—More satisfactory methods of securing colored surfaces are by the employment of colored clay, colored tile or mosaics embedded in the concrete. Colored tile has been used with marked success. There are several methods by which these clays can be inserted in the concrete.

Tile may be first glued to perforated forms with common bill-posters' paste and the mass concrete deposited as usual. When the concrete has properly set, wetting the forms with water will dissolve the paste so as to allow the removal of the forms. Before the forms are removed they must be thoroughly flushed with water. Such tile work can also be slabbed in sections at the pottery, and the slabs transported and nailed to the forms, the mass concrete being deposited as usual. Copper tacks are sometimes used to secure the slabbed tile to the forms or centering, no discoloration from rust taking place with the lapse of time where copper tacks have been used. A piece of felt should be placed between the form and the face of the mosaic, if such be used, in order to prevent the smaller particles of grout from running onto the face of the mosaic and staining it. The prepared ornamental slab is then backed up and surrounded by a firm body of concrete.

Another method of inserting tile or pattern work is to place them piece by piece in the wall after the removal of the forms, in which

case sunken panels from 1 in. to 1½ in. deep, of an outline to suit the design, should be provided for their reception. These panels are then filled in at any convenient time with the tiles bedded in cement mortar. In providing space into which to set tiles, pieces of wood of the exact size of each tile, or tile work slabbed in sections, should be nailed lightly to the forms, so that the forms can be removed without pulling them from the concrete. When the forms are removed these pieces of board will remain in the surface of the concrete, and should be left in until whatever surface finish desired for the remainder of the work has been completed. They are then removed, thus leaving recesses conforming to the design, and the tiles or ornamental slabs are placed in these recesses, being cemented in with a mortar varying in color to conform with the design (see page 391). Belt courses around columns or along façades, ornamental medallions, and innumerable other points have been beautifully ornamented by this means.

Brick Veneering or Facing.—The concrete must be true to line and level, as it is otherwise difficult to put on a brick facing. It is very important that suitable play be provided for, as brick cannot be made to exact dimensions, while the concrete construction is very apt to vary slightly from the specified dimensions.

Care must be taken to embed a sufficient number of metal ties for tying the face brickwork to the concrete. Bolts must also be placed in the concrete to receive the angle irons which carry the brick work over door and window openings. One galvanized wire wall tie should be used for about every 2 sq. ft. of surface, except in earthquake countries, where there should be one every square foot. Wire ties should be at least ⅛ in. in diameter, with one end bent. One end of the tie should be thrust through a small hole in the forms immediately after the concrete is placed and before it has set. Upon the removal of forms the projecting end of the tie should be bent at right angles and embedded in the mortar between the bricks. It is advisable to make all ties of soft iron, so that they will not break when adjusted.

In laying brick masonry every brick must be cleaned and thoroughly saturated with water, and should be laid in the best hydraulic cement mortar (proportions of 1:2), with such thickness of joint and style of bond as prescribed by the engineer or shown on the plans. No broken bricks should be used in the face of any wall, except when necessary to make closures for properly dimensioning the several courses or to break joints.

Terra Cotta Facing.—The concrete must be true to line and level, as it is otherwise impossible to put on the terra cotta facing. It is very important that suitable play be provided for, as terra cotta cannot be made to exact dimensions, while the concrete construction is very apt to vary slightly from the specified dimensions.

The arrangement of the ties and supports for terra cotta varies greatly with the design. Usually a hollow space is left between the concrete and the terra cotta facing. Cement mortar deposited in this space ties the facing to the concrete behind, as the facing blocks have

projecting ribs on the back, while iron anchors project from the concrete, so that the whole is locked securely together. At intervals supported ledges must be arranged to transmit the weight of the terra cotta facing (which is considerable) to the structural concrete.

Stone Facing.—If stone facing is used for concrete work, the stones should be of an approved quality. The stone must be of a compact texture, free from loose seams, flaws, discolorations or imperfections of any kind, and of such a character as will stand the action of the weather. The stone facing should in all cases be securely bonded or clamped to the concrete backing. All stones should be dressed to true beds and vertical joints, unless otherwise desired. No joints should exceed ½ in. in thickness and should be laid to break joints at least 9 in. with the course below. All joints should be cleaned, wet and neatly pointed. The facing stones should be in true line, and to the dimensions given on the plans. All cornice, moldings, capitals, keystones, brackets, etc., should be built into the work in the proper position, etc., and should be of the forms and dimensions shown on the plans.

CHAPTER VIII

INSPECTION OF WATERPROOFING FOR CONCRETE WORK

It is foreign to the purpose of this chapter to consider the designing of waterproofing systems, which presupposes that the designer is thoroughly familiar with the physical and chemical nature of the materials he proposes to employ, and their effect upon the concrete structure, etc., but simply to give such general and specific instructions as are necessary to insure proper and adequate inspection of waterproofing after the plans and specifications are completed and the contract let.

Failures to make concrete waterproof are due to faulty details, poor workmanship, poor materials and the formation of cracks in the masonry. Poor workmanship and neglect of correct principles of construction are responsible for practically all failures that occur in this class of work. Failures which can be positively charged to poor materials are few, though frequently materials are used which could be improved by a more careful and intelligent selection, without adding to the cost of the work. The use of a waterproofing ingredient or application tends to poor construction work, the contractor counting upon the waterproofing to help out careless construction.

Art. 46. Waterproofing Materials

For all outside concrete work, like walls, roofs, etc.; for basement floors and walls, and for tanks, cisterns and similar construction, the concrete should be rendered waterproof. In other words, except for mass concrete foundations, all work should be made as water-tight as possible.

Specifications for Waterproofing.—Specifications should be particular and explicit regarding the method to be employed for making concrete water-tight. They should be suited to the conditions surrounding the particular job so as to obtain a structure that will be entirely free from dampness and the percolation of ground or outside water. It is a mistake to leave the work entirely to the contractor by not specifying the exact materials and the methods to be employed, as is quite often done. The specifications must be clear in the matter of indicating what is absolutely required without any alternative, and what is named as indicating in general the character of the product, and in which alternative materials, methods or results will be allowed. In other words, the contractor should know in advance how the waterproofing specifications are to be inter-

preted, so far as it is possible to give this information in the specifications. In case they are not clear, the inspector should learn from the engineer the quality of work he has in mind and should see that the contractor clearly understands the requirements.

NECESSITY FOR INSPECTION OF WATERPROOFING

Inspection of Waterproofing Materials.—Although there is a tendency among manufacturers of waterproofing materials to improve the quality of their product, yet this does not relieve the necessity of careful inspection of waterproofing materials delivered for important concrete work. Before cement is allowed to go into the work, it is generally tested either at the site or sent to some laboratory for testing (see Art. 3, page 27). Sand and broken stone or gravel are usually carefully examined for cleanliness, etc., for concrete (see Arts. 8, 9 and 10), but how often is the trouble taken to find out whether the waterproofing materials specified have been supplied, or these substituted by a cheap material? There is nothing easier than the substitution of poor materials for good ones by irresponsible contractors or dealers, particularly when the price is much below the standard price for like materials. Why should not these materials be tested as they come on the work, in the same way as other construction materials are tested? Why pay for asphalts when oil substitutes are being made? Why accept soap or powdered lime when waterproofing compounds or proprietary ingredients are being bought? On large works particularly, materials specified for waterproofing purposes should be subjected to the same degree of inspection and tests as other construction materials.

Engineers should not consider the careful inspection of waterproofing materials as an additional refinement in connection with rendering concrete water-tight, but as an absolute necessity, and should establish the unconditional rule of not permitting any waterproofing material to go into their work until they are fully satisfied by careful inspection that the material is of good quality and capable of giving them the very best results. So many of the coal tar and asphaltic preparations look alike that the quality of the material delivered can be ascertained only by subjecting them to specified tests, fixed according to the character of the work in hand. Waterproofing felts and other fabrics should also be examined for defects (see page 451), and powders and other materials to be introduced as a part of concrete work should be tested and compared with samples obtained, to see that the material is actually delivered (see Art. 48).

Results of Incompetent Inspection.—In applying waterproofing, success depends on the perfection of every detail. Are these details looked after as they should be? Usually not. How many inspectors can tell whether the concrete surfaces are too wet, or too rough, or in a proper condition to receive the waterproofing? The best materials, applied to improperly prepared surfaces, are worthless. How many inspectors can tell whether the waterproofing materials specified have been supplied, or these substituted by a cheaper material?

All asphalts, tars and black paints look alike and to many are one and the same thing, and for lack of competent inspection the best designed waterproofing systems may result in a complete failure.

Why is it that bad conditions are often discovered in waterproofing concrete structures where the plans and specifications have been all that they should be? It is because the work is done by incompetent and inexperienced workmen—defective material, good work not properly protected, or even injured, or conditions unsuited to the work. After the structure is completed and leaks are discovered, the engineer puts the responsibility on the contractor, he in turn on the engineer's inspector. In fact, there is a general shifting of responsibility. The result is a loss to all concerned, in money and in reputation.

Intelligent Inspection Needed.—Success with any system of waterproofing requires considerable supervision on the part of an intelligent superintendent or inspector who has a practical and technical knowledge of the work in hand. It is a very serious mistake not to place in charge of the waterproofing an inspector who thoroughly understands such work.

In order that waterproofing materials of the desired quality be obtained, certain requirements are usually outlined in the specifications, and it is incumbent on the inspector to see that these requirements are fulfilled as far as it is within his power to do so. Laboratory tests should be made on the waterproofing material delivered on the work as mentioned above in order to determine whether physical and chemical requirements are satisfied.

So many failures have been reported from the application of waterproofing when the walls were not in a proper condition to receive the waterproofing, and from the failure to protect the waterproofing from injury due to unnecessary exposure, back-filling or other causes, that a competent inspector should be always on the work and no work done in his absence. In other words, a competent inspector should be present from the inception of the waterproofing work to its completion, and nothing done, and no tampering or interference allowed without his knowledge.

It cannot be too strongly insisted that there be proper and adequate inspection of waterproofing at all times during the construction of the work. All efficient waterproofing is dependent, to a large extent, upon the quality of workmanship in its application. The materials must be carefully placed by skilled workmen and a common and serious mistake is often made in attempting to do the work with incompetent and inexperienced workmen. All the more reason why we should have intelligent inspection. With proper and adequate inspection, where the plans and specifications are all that they should be, the waterproofing of concrete structures becomes as certain and permanent as possibly can be expected.

The inspector will find it one of his hardest duties to secure successful results in the matter of making concrete water-tight. The supervision must be constant and efficient.

METHODS OF WATERPROOFING CONCRETE

Classes of Waterproofing.—The various methods of rendering concrete waterproof may be classified under two broad divisions as follows: (1) The *Integral,* in which the concrete is made impermeable or waterproof prior to setting; (2) *External* or *Surface Treatment,* in which the concrete is surrounded by a protective shield, or in which the waterproofing is applied to the surface of the concrete.

Both of these methods may be—and in many instances are—effectively combined in the same construction.

Methods of Waterproofing.—The above two classes of waterproofing concrete may be further subdivided into a number of special types or methods of waterproofing, differing from one another in marked characteristics.

Integral methods, for example, comprise two subdivisions, as follows: (1) Accurately grading and proportioning the aggregates and the cement so as to secure a concrete so dense as to be waterproof; (2) Mixing some substance with the concrete, such as hydrate of lime or a manufactured compound, to make the mixture water-tight.

Surface Treatment methods of waterproofing may be subdivided according to the materials used, as follows: (1) Applying a waterproof coating to the concrete after it is in place, such as alum and soap washes, grout washes, cement mortar coating, asphalt coating, etc.; (2) Surrounding the concrete structure with layers of waterproofing materials, such as asphalt and felt, to keep the water away.

For brevity, the above methods will be designated: (1) Dense or Impermeable Concrete; (2) Introduction of Foreign Ingredients; (3) Special Treatment of Surface—Coating Surface; (4) Layers of Waterproofing Material—Membrane Method.

It is often advisable to combine two or more of these methods. Directions and suggestions for practically applying these methods will now be taken up in the following articles.

Art. 47. Dense or Impermeable Concrete

Concrete masonry, properly designed and placed, may be made practically waterproof under moderate pressures without the addition of special waterproofing materials, but success requires much care. Where concrete is to be made water-tight without additional treatment or introduction of waterproofing ingredients, the aggregate should be so selected as to have a minimum of voids. A dense, even mixture of concrete should be the primary expedient to secure water-tight concrete. In general, it may be stated that in monolithic construction a wet mixture, a rich concrete and an aggregate proportioned to secure great density will in the majority of cases give the desired results, and is satisfactory for massive work, and for many structures where the conditions of construction can be readily controlled. For other cases, especially where the pressures are high, additional precautions are desirable (see Arts. 48, 49 and 50).

While the method of waterproofing concrete by so proportioning

the concrete itself that it is impermeable would appear to be an ideal one, yet the method has some bad features which it would not be out of place to mention in this article. In the first place, it is more difficult to proportion the concrete carefully in field work than it is in the laboratory; and while samples of concrete made in the laboratory might seem impermeable, it is doubtful whether the same concrete would also seem impermeable when made in the field, especially when made by some contractors. Then, again, to obtain a concrete that is entirely impermeable, it must be made fairly rich as mentioned below. Under these conditions, it would often have more strength than is really required. In other words, to gain waterproofing qualities, it is often necessary to use a better concrete than would otherwise be required. Such a procedure, of course, would not be economical. Concrete, when properly mixed, is waterproof only up to a certain degree. If the water is under great pressure, as at the bottom of very deep foundations in the very wet soils, it is probable that moisture will gradually soak through the concrete. Another objection that should not be overlooked is the liability of the concrete to crack; this may happen even if waterproofing compounds have been added. While this danger is under control today, every precaution should be taken to avoid it.

Leakage in tanks and reservoirs may be due to faulty construction as follows: (1) Lean and porous concrete work; (2) Inexperience and carelessness in carrying out the construction.

PROPORTIONING AND LAYING WATER-TIGHT CONCRETE

Proper proportioning of ingredients, proper grading of aggregates, thoroughness of mixing, and careful methods of placing are factors of the utmost importance in securing a dense concrete which will be impervious to water under moderate pressures.

Grading of Aggregates.—In concrete, the volume of mortar should exceed the volume of voids in the aggregate, and to obtain this result without too great expense the aggregate should be so selected as to have a minimum of voids. The advantage of grading is to minimize the voids and reduce the actual surface area of the aggregate to which the cement must adhere. In this connection see Art. 13.

Proportioning Water-Tight Concrete.—The exact mixture to use in order to secure impermeable concrete will depend on the quality of sand and broken stone or gravel, and it is only by experimenting with the same quality of sand and broken stone or gravel that is to be used that this ideal mixture can be arrived at. In other words, for this purpose a rich mixture should be used of such proportion of sand and stone as to produce the maximum density. Mixtures from 1 cement and 3 of sand and stone to 1 cement and 6 of sand and stone will usually give satisfactory results for moderate pressures. However, with accurate grading by scientific methods (see page 147), water-tight work may be obtained with 1 cement and 10 of sand and stone. A richer mixture than 1:3 is liable to crack or check. The proportions usually employed to prevent percolation are, with

ordinary materials, 1:2:4; and with well-graded materials, 1:2:6, or 1:3:5. In other words, with well-graded aggregates a somewhat leaner concrete can be used.

Gravel concrete properly proportioned may be made water-tight somewhat more easily than broken stone concrete, but a mixture of gravel and broken stone will give good results not only in this regard but in the matter of strength as well. A mixed aggregate evidently has fewer channels through which the water can pass than an aggregate consisting of broken stone and sand, provided the character and relative proportioning of the finest particles are the same in both cases.

The water-tightness of concrete depends principally upon the amount of cement present, provided the sand and broken stone or gravel are properly proportioned. Six bags of cement per cubic yard of concrete is ordinarily sufficient to produce a water-tight mixture. This amount, however, should be increased when the hydrostatic head is considerable.

Size of Aggregates.—Concrete made with large aggregate is much more impervious than that containing only smaller sizes. Coarse aggregate, ranging from ½ in. up to, say, 2½ in., is far superior to aggregate ranging from ½ in. to 1 in. It is sometimes claimed, however, that the fine material can be placed more satisfactorily. This depends upon the workmanship. With proper selection of materials and care in laying, concrete made with large aggregate will produce excellent results. If a very fine broken stone, under ½ in., and containing crusher dust, is used for the coarser aggregate, the addition of sand may increase the porosity and the permeability, because concrete containing such small stone is practically a mortar, and the finer particles of stone or crusher dust are really sand.

Thickness of Concrete for Water-Tight Work.—The thicker the wall the less water will flow through it in proportion. It is impossible, however, to specify definite thicknesses to prevent percolation under different heads of water, because of variations in proportions used for concrete work and methods of laying. Rainwater under a head of 3 in. has been known to percolate through a 4-ft. wall of excellent concrete and dry consistency, while a 3-in. wall under a 4-ft. head of water has proven perfectly tight.

Mixing Concrete.—The mixing of concrete should be done with great care to secure a thoroughly homogeneous mass. In this connection see Art. 15.

Consistency of Concrete.—A rather wet mixture should be used in preparing concrete when water-tightness is desired, as wet mixtures do not pass water as readily as dry ones. On no account should a dry mixture be made if intended to be water-tight. That is to say, the concrete should have a "quaking," jelly-like consistency, or even made with enough water to be somewhat "mushy" or "sloppy." In other words, the best way to keep water out of concrete is to put lots of water in it in the manufacture. However, a concrete may be too wet to produce the most impermeable product, if impermeability is sought. On the other hand, a deficiency of water will result in a much more permeable mass than the use of what might be considered an

excess. The author wishes to emphasize the importance of using the right amount of water. It is not possible here to state what percentage of water should be used, as it varies with different cements and aggregates and should be determined by experiments for any particular combination that is to be used. In this connection see page 193.

The concrete should be so mixed that it will just carry the man ramming, and which when walked or tamped on by him will cause it to "quake," so that it will settle into place with only a small amount of ramming. If the concrete is mixed with too little water, it cannot be rammed into a very compact mass with ordinary ramming tools. With the wet mixtures of concrete now generally used in engineering work, concrete possesses far greater density, and is correspondingly less porous, than with the older, dryer mixtures.

Placing Concrete.—Great care should be exercised in handling concrete (see Art. 25, page 290). While the materials employed may be perfectly graded, properly proportioned, and thoroughly mixed with water, yet if improperly placed, the concrete is likely to leak. Concrete must be carefully placed so as to leave no visible stone pockets (see Art. 41, page 384).

It would be much better if the entire structure could be made one continuous operation, but as this is usually impracticable except for small pieces of work, joints due to stopping of work must be made with great care (see Art. 26). In other words, for a small structure which must be water-tight, it is advisable to place the concrete continuously, allowing no joint whatever, and not even permitting the concrete to stiffen up between the batches. Even an interruption of an hour in the middle of a hot day has been known to form a joint which will allow water to pass. If continuous work is impracticable, the old surface of the concrete must be thoroughly cleaned of all dirt and partially set cement, for whenever partially set cement is left on old concrete trouble invariably occurs, in order to expose the aggregate. The unfinished surface should always be left in as rough a condition as possible, but never roughened up after the concrete has partially set. The author has found that this roughening often loosens the stone in the concrete, but not sufficiently so that they can be removed, a condition which is apt to impair the water-tightness of the structure.

To start a day's work, the surface should be thoroughly scraped with wire brushes and kept wet until the next course is ready (preferably being covered with wet sand or bagging) and carefully swept just before fresh concrete is placed upon it. A mixture of common muriatic acid water in the proportion of one acid to three of water should be used to clean the old surface of the joint, after which the acid should be thoroughly washed away before applying the fresh concrete. It is recommended that a layer of soft cement paste or else 1:1 mortar be spread upon the prepared surface after thoroughly soaking it. The fresh concrete must be laid before the mortar shows signs of stiffening. For other methods of bonding new to old concrete, see Art. 27. Void the formation of joints through which water

will pass by making an effective bond between successive days' work. A cement liquid mortar mixed in the same proportions as the mortar in the concrete is sometimes used, being poured over the old work to a depth of ½ in. This method always gives a good water-tight horizontal construction joint.

The concrete should be allowed to dry slowly, being well protected from the direct rays of the sun. This can be accomplished by covering the concrete, in the case of vertical walls, with burlap, which is kept wet by sprinkling for about a week or by keeping wet sand on horizontal surfaces. In this connection see Art. 29.

Contraction Joints.—Where the work to be waterproofed is of much magnitude there is danger, should the concrete itself be made water-tight, that with the aging of the concrete shrinkage cracks will develop and thus nullify the waterproofness of the concrete by causing seams through which the water can percolate; consequently, when work is to be made water-tight, suitable provision should be made for contraction by special joints (see Art. 28), or by steel reinforcement without joints. Shrinkage and temperature cracks should generally be prevented by reinforcement.

Making Good Defects.—Any places showing rough or any points where leakage occurs should be plastered with a coat of 1 to 2 cement mortar, into which may be mixed some waterproofing ingredient (see page 426), approved by the engineer, and the wall left in a water-tight condition. For methods of patching and repairing defective concrete surfaces, see Art. 30, page 338.

Action of Water on Porous Concrete.—When water is permitted to percolate continuously through a mass of concrete, particularly that which is very dense, the permeability will decrease in a marked degree. Usually after the flow of water has continued for a few hours, it is found to diminish rapidly in quantity, apparently due to the filling of the pores with very fine particles of clay and other material carried in suspension by the water, gradually making it more waterproof. If this action takes place at all, it is produced very rapidly. On the other hand, if it is not thus rapidly produced, the effect of the water is apt to be injurious, because it and the chemicals it contains will dissolve certain parts of the concrete which will then be carried away and the whole mass become honey-combed, even to the point of failure.

The author has frequently observed that when concrete was green, there was a considerable seepage through it, and that in a short time absolutely all seepage stopped.

RICH MORTAR COATINGS

A rich mortar facing is practically impervious to water, especially if it is all troweled until a dense face is secured. Lime paste is sometimes added for smoothness in working. It is essential that the facing be well troweled.

Rich Mortar or Granolithic Finish.—For many places where a surface must be waterproofed a rich mortar carefully applied by

skilled workmen will not only answer the purpose of a finished appearance but will resist a water pressure of a number of feet head. Plastering with rich mortar is effective provided cracks can be prevented. This is very difficult to accomplish unless the plaster is applied to the concrete before it has set, as the variation in temperature and moisture between concrete and plaster is almost certain to cause a separation. There is some danger, however, when such a surface coating is used of its cracking and peeling off if exposed to the direct rays of the sun. If it is covered with water, as in the bottom and sides of a reservoir or tank, no danger of this kind should be apprehended. Preferably only structures which will be permanently submerged or moist should be plastered for watertightness. Even then good results can only be obtained by experienced and skillful workmen under intelligent supervision.

On horizontal or inclined surfaces, a mortar finish of Portland cement and sand, or Portland cement and screenings in proportions of 1:1, or 1:2, may be laid and troweled, as in basement floors, sidewalks, reservoirs and tanks. This should be laid while the concrete base is still green, and with the same that is, Portland cement, and carefully troweled in place (see page 478). The granolithic finish varies from ½ in. for floors to 2 in. for concrete pavements.

Troweled Surface.—Where the concrete can be worked before it has set, the surface may be troweled until a dense mortar face is secured. Troweling brings the cement to the surface, and produces a dense, hard surface, which is practically equal to a surfacing of rich mortar. For a vertical surface the forms must be stripped while the concrete is still green enough to be worked with a trowel. The surface should be troweled hard and smooth; but excessive troweling is likely to cause innumerable hair cracks in the finish surface (see Art. 51, page 484). The scope of this method for vertical surfaces is limited to instances where the forms can be quickly removed, or removed in sections. No trouble need be experienced with horizontal or inclined surfaces, as the mortar finish would be placed at the same time as the concrete base. (See page 389.)

Troweling is very effective for the top surface of an arch and the exposed surface of a sea wall or the inclined face of a dam.

Art. 48. Introduction of Foreign Ingredients

Concrete may be made impervious to water by adding some finely divided material which will fill the minute pores which form in the concrete as it hardens. As has been said on page 421, extra cement will do this or by theoretically proportioning the ingredients to eliminate the voids. For many conditions this is all that is required, but no matter what the richness of the concrete may be, there is always the probability of improper setting, and in many cases it is advisable to add water repellents and finely divided foreign materials to obtain waterproofness. There are two methods of rendering

concrete water-tight by the introduction of foreign ingredients, viz.: (1) Adding a single inert void-filling substance; and (2) Adding one or more substances which by action upon the cement or between themselves may produce a void-filling material.

There are two distinct classes of void-filling materials: (1) Those that have a capillary attraction for water, i. e., lime, puzzolan cement and clay, which reduce permeability by obstructing the voids; (2) Those that have a capillary repulsion for water, i. e., alum and soap, wax, and a number of proprietary compounds.

Inert Fillers.—The first class of this division of compounds comprises all the inert fillers; that is, those materials which act as void fillers or increase the density of the concrete and are without any action on the cement and do not themselves change. In this class may be included hydrated dolomitic lime, clays, finely ground sand, and finely ground feldspar. Some of these compounds may be partly changed in time when in the concrete. The hydrated lime may be partly carbonated, especially on the surface, the feldspar may decompose by the leeching out of the alkalis; the sand will change but very little, being a high-grade quartz sand; the clays will be very inert, although some theories have been brought forward which assume a very important rôle for clay when mixed into concrete.

Active Fillers.—There is but one compound in this class. It is a white powder with a strong aromatic odor of kauri resin. This being in combination with potassium will possibly partly dissolve in the mixing water and in turn be decomposed by the lime present to the corresponding lime resinate, which is comparatively insoluble. The greater part of the compound is entirely inert, being china clay and hydrated lime.

Water-Repelling Compounds.—In this class of compounds we have stearic acid (see page 434) combined either with soda and potash or lime. The amount of these necessary to combine with the acid is not very great, seldom exceeding 7.5 per cent. Consequently it can be seen that the greater part of the material is hydrated lime and magnesia lime. These act simply as void fillers. As a whole, they are inert toward the cement and water. However, those in which the stearic acid is combined with the soda and potash must react with the lime of the compound to form the more insoluble lime soap, or else they are valueless, owing to the ready solubility of the former soap in water.

Waterproofing Ingredients.—Various materials may be mixed with the concrete to reduce its porosity. The compounds that are incorporated into the concrete while it is being made depend, as a rule, on the chemical formation of a lime soap, which fills the interstices of the concreto. The principal advantage of adding foreign ingredients or void-filling material into a mortar or concrete is to permit the use of a lean mixture, the fine particles of the waterproofing ingredients tending to reduce the volume and dimensions of the voids. In case of a rich concrete, the cement generally furnishes enough fine material to fill at least the larger voids.

HYDRATED LIME

One of the most common materials used for waterproofing with considerable success under all ordinary conditions is lime. It can be thoroughly slaked and mixed with concrete as a putty, or better, thinned to a whitewash. Another form producing similar results is hydrated lime, which is commercial or common lime subjected to the action of clean water until the lime is thoroughly slaked, dried and pulverized to a fine powder, and mixed dry with the mortar. Hydrated lime is much finer than the finest Portland cement; hence the material fills the voids in the concrete mass, making a denser and therefore more nearly waterproof substance. The lime possesses the property of coating each particle of sand and filling up all the voids around it, by crystallizing in the pores of the concrete, and in this way makes the concrete waterproof.

The great advantage accruing in using hydrated lime as a waterproofing material over other substances lies in the fact that while most of these latter substances decrease the ultimate strength of the cement from 5 per cent to 20 per cent, the hydrated lime does not decrease it at all, but rather increases it.

While hydrated lime assists in making the concrete waterproof, it must not be thought that by its addition all cares as to the mixing of concrete, the amount of water used, and the placing of the concrete may be dispensed with. These precautions must be taken just the same as if the hydrated lime were not added. See page 435.

What Hydrated Lime Is.—Hydrated lime is practically pure calcium hydrate, is of mineral nature, contains no organic material and is, therefore, not subject to decay or disintegration. It is a white, soft-feeling, smooth powder that is light in weight and looks like flour. For equal weights it occupies about two and one-half times the bulk of cement. Hydrated lime is commercial lime subjected to the action of clean water until the lime is thoroughly slaked, the water afterwards being driven off and the lime reduced to fine powder. Quicklime in sizes of 1 in. and under is used, and the water well stirred into it. The heat generated drives off the water and the residue, if not sufficiently fine, is ground to powder. Hydrated lime is sold in sacks and costs about the same as cement.

Proportioning Hydrated Lime.—The percentage of hydrated lime to use varies with the proportions of concrete and the character of the materials. If fine sand is used instead of coarse sand, a smaller quantity of lime will be required. The amount of lime to be employed is usually given as a percentage, by weight, of the cement. The percentage of hydrate of lime used in practice varies from 5 per cent to 17 per cent of the weight of the cement. For a 1:2:4 concrete, add dry hydrated lime equal to about 8 per cent of the weight of the dry cement; for a 1:2½:4½ concrete add about 12 per cent; for a 1:3:5 concrete add about 15 per cent, and for a 1:3:6 concrete add about 17 per cent. The addition of hydrate of lime in the above proportions will render concrete practically water-tight under a pres-

sure of 60 lbs. per sq. in. Smaller per cents will give satisfactory results under smaller pressure. About 10 per cent of hydrated lime will give good results under ordinary conditions without impairment of strength in the resulting concrete. (See pages 394 and 522.)

If possible a good plan is to test the permeability of the concrete that it is intended to use on a certain structure with various percentages of hydrated lime before the work is started. In other words, secure a few pounds of hydrated lime and note the difference resulting from its incorporation in the mixture.

Mixing Lime.—For the waterproofing of concrete, pure calcium hydrate, or hydrated lime, as it is called, must be added to the cement. It should be dried and pulverized, however, before adding it to the cement, and in slaking it must be thoroughly mixed with the water in order that no unslaked lumps will remain. Too much water must not be used in slaking, as the extra water is difficult to remove and some of the lime is liable to be deteriorated by it. At present few contractors slake their own lime, because lime slaked by special machinery, reduced to a fine smooth powder and packed in bags, can be bought in the market as mentioned above.

The hydrated lime and cement should be thoroughly mixed dry before placing in the mixer, as the lime will be more efficacious acting directly on the cement, rather than be dissipated through the aggregate. If the hydrated lime is mixed wet the putty should be so thinned that it can be as easily and uniformly distributed through the whole mass as is the water. Since hydrated lime is a very fine dry powder, it can be very easily mixed with the concrete. If good results are to be obtained with the use of hydrated lime, it must be mixed thoroughly with the dry cement. After the cement and lime are mixed until the color of the mixture is uniform, the sand, broken stone or gravel, and water should be added as usual (see Art. 15).

For very rich mixtures of concrete, when hydrated lime is to be added, it is well to reduce the amount of cement employed; that is, with rich mixtures, instead of adding the lime as in ordinary mixtures, it is better to substitute the lime for part of the weight of cement.

PUZZOLAN CEMENT

Puzzolan cement being largely composed of lime acts substantially the same as lime in making concrete water-tight, except that lime adds very little to the strength of the concrete, while puzzolan cement adds considerable strength. Mixtures of Portland and puzzolan cements have been found to well resist the action of sea water.

Proper Uses of Puzzolan Cement.—The action of puzzolan cement is not mechanical alone, but chemical, and the effect on the strength of the resulting mortar or concrete depends upon the exposure to which it is subjected. The oxidation of sulphides in dry air is destructive of puzzolan cement mortars and concretes so exposed. It will turn white and disintegrate, due to the oxidation of its sulphides

at the surface under such exposure. However, puzzolan cement is especially valuable for waterproofing concrete to be exposed to sea water, since it is not acted upon by the sulphides in the sea water.

COLLOIDAL CLAY

In place of hydrated lime, concrete is often waterproofed by mixing with it finely ground colloidal clay. The addition of pure clay, finely powdered and free from any trace of vegetable matter, materially increases the water-tightness of concrete by acting as a void filler, especially of lean mixtures; but the concrete is not necessarily free from absorbing moisture.

Effect of Clay.—The effect of clay varies with the richness of the mortar, i. e., with the proportion of cement. Clay is ineffective with rich, well-proportioned concrete, since the cement furnishes fine material to fill the voids. The clay, if finely pulverized, helps to fill the voids of the sand and causes the cementing material to coat the grains better and thus bind them more strongly together. The exact effect of the clay, however, depends chiefly upon the fineness of the sand grains and upon the per cent of the voids in the clean sand; but depends also upon the thoroughness of mixing and the amount of water used, for if the clay forms a coating on the sand grains and is not removed in the mixing, a small amount of clay is deleterious. Moderate doses of clay have no deleterious effect on the strength of mortars or concrete for ordinary exposures (see Art. 8, page 91).

The presence of the clay retards the setting of the cement—natural usually more than Portland—and makes the mortar more susceptible to the action of frost.

Percentage of Clay.—Finely divided colloidal clay, in proportions running from 5 to 15 per cent, produces a fairly efficient waterproofing effect in concrete. The proportions should vary with the character of the aggregates and the richness of the mortar, i. e., with the proportion of cement. In certain cases 5 per cent of clay to the weight of the sand has been found effective. With lean concretes, from 10 to 15 per cent of finely powdered clay, either added directly or by the substitution of a dirty for a clean sand, increases the water-tightness without materially decreasing the strength.

Fineness of Clay.—The clay should be finely divided—preferably to diameters that will entirely pass a 200-mesh sieve.

Mixing Clay.—Success with the use of clay depends upon the thoroughness with which it is incorporated into the concrete. The clay must be thoroughly dry and well mixed with the cement. If this precaution is not taken, the clay is liable to roll up into little balls. Even distribution throughout the mass is absolutely necessary. The greater the proportion of clay, the more thorough should be the mixing.

Use of Clay and Alum Sulphate.—Clay may be used in combination with alum sulphate for increasing the water-tightness of concrete.

PULVERIZED ROCK

Rock pulverized as finely as Portland cement has been used to increases the water-tightness of concrete, especially of lean mixtures.

Use of Pulverized Rock.—For mortars not richer than 1:3, and concrete made with these proportions of cement and sand to the stone, the impermeability may be increased by the addition of rock pulverized as finely as the cement and equal to it in weight. If, however, the natural sand is very fine or contains dust, the addition of pulverized rock is not so beneficial.

ALUM AND SOAP

Alum and soap may be used as ingredients of concrete for increasing water-tightness. This is usually referred to as the "Sylvester" mixture, which is an old one, but it has proved successful on many occasions. The alum and soap combine and form a flocculent, insoluble, water-repelling compound. Not only are the voids partially filled by this capillary repellent compound and thereby decrease the permeability of the concrete, but the permeability is further decreased by the water-repellent property of the compound. In other words, the alum and soap mixture deposits aluminum silicates (an insoluble gelatinous mass) in the voids of the concrete. While the concrete is rendered more impervious by this mixture, it is also somewhat weakened. (See page 443.)

Proportions of Alum and Soap.—Various proportions of alum and soap have been used. The best proportions are: alum 1 part and hard soap 2.2 parts, both by weight. These proportions are the chemical combining weights for alum and the best hard soap, and are exact enough for any good, well-seasoned hard soap. Soap varies in the amount of water it contains, and where soft soap is used, a greater proportion should be employed according to the amount of water in it. Soft soap contains from 55 to 95 per cent water. An excess of soap is preferable to an excess of alum, since the excess soap will unite with the free lime of the cement and form calcium soap, which is a finely divided, water-repelling compound. An excess of alum, however, does no harm, since alum is itself a fair waterproofing material. This may account for the reason why widely divergent proportions of alum and soap have given fairly successful results in practice.

Approximately 1 per cent, by weight, of powdered alum may be evenly mixed with the cement, and the same proportion of soap may be dissolved in the water in making the concrete. The amount of alum and soap is practically limited to alum equal to 1½ per cent of the water and soap equal to 3 per cent, because it is impossible to dissolve more than about 3 per cent of hard soap in cold water. Where it is desirable to use greater amounts, the soap may first be dissolved in hot water, which may afterwards be mixed with a large portion of cold water. Alum equal to 1½ per cent of the water and soap equal to 3 per cent, is enough to render any reasonably dense concrete practically, if not absolutely, waterproof.

Mixing Alum and Soap.—The alum in the form of a fine powder may be mixed with the cement, and the soap may be dissolved in the water used in mixing the concrete; or both the alum and the soap may be dissolved in the water. In the latter case the water should be frequently stirred to prevent the compound from accumulating in large masses on the surface, which it is not easy to break up. Even distribution throughout the water is absolutely necessary. Since the alum is the more soluble, it may be dissolved in, say, one-fifth of the water and the soap in the remaining four-fifths. The two portions may then be mixed together, care being taken to stir the water thoroughly as the mixing progresses. The mortar is made wet, and the broken stone or gravel is added in the usual manner. Success in the use of alum and soap depends upon the thoroughness with which it is incorporated into the concrete. Even distribution throughout the mass is absolutely essential for rendering concrete water-tight. Ordinary precautions should be taken to make the concrete dense (see Art. 47), and as a rule the concrete should be mixed rather wet.

ALUMINUM SULPHATE AND SOAP

Aluminum sulphate (sometimes, but improperly, called alum) and soap has been found to increase the water-tightness of concrete. Aluminum sulphate is cheaper than alum.

Proportions of Aluminum Sulphate and Soap.—The best proportions are 1 part aluminum sulphate to 3 parts of hard soap. An excess of soap is better than an excess of aluminum sulphate, since the excess soap will unite with the free lime of the cement and form calcium soap, which is a finely divided, water-repelling compound. An excess of aluminum sulphate, however, does no harm, since aluminum sulphate is itself a fair waterproofing material.

Mixing Aluminum Sulphate and Soap.—Success in the use of aluminum sulphate and soap depends upon the thoroughness with which it is incorporated into the concrete. Even distribution throughout the mass is absolutely necessary.

LIME AND SOAP

Lime and soap may be used as ingredients of concrete for increasing water-tightness. The lime and soap combine and form calcium soap, which is a finely divided, water-repelling compound. Calcium soap is a product in the manufacture of candles and may be bought and added directly to the cement. It is the essential element of several proprietary waterproofing compounds.

Proportions of Lime and Soap.—According to Prof. Ira O. Baker in his book on "Masonry Construction," 1909 edition, the proper proportion is unslaked lime 1 part and hard soap 12 parts; but, since it is impossible to dissolve more than about 3 per cent of hard soap in cold water, the amounts to be used in practice are unslaked lime 0.25 per cent and hard soap 3 per cent of the weight of the water. These proportions will give 2.7 per cent of void-filling com-

pound and will render any reasonably well-graded concrete absolutely water-tight.

Mixing Lime and Soap.—Before the water containing the lime and soap is used, it should be thoroughly stirred to mix the ingredients and to keep the precipitate in suspension.

PROPRIETARY COMPOUNDS

There are many patented materials on the market, sold under various trade names, and intended for direct incorporation in the concrete mass, in order to render it water-tight. The majority of these compounds are in powder form, to be added dry to cement before mixing. These are usually of white, floury consistency, extremely fine, and are water-repellent. The water-repellent properties are imparted by the introduction of a metallic stearate (see page 434), such as lime soap, which is of a fatty nature. Being so extremely fine, they have a distinct void-filling property, and their uniform distribution in the cement gives a denser mixture. In addition to the metallic stearates, they contain varying proportions of hydrated lime and alum. The latter materials are themselves extensively used to waterproof concrete as mentioned on pages 428 and 431. Some proprietary compounds are sold mixed with Portland cement ready for use, where the addition of special materials and special treatment a water-repellent cement is obtained. Apparently the waterproof qualities of this cement are obtained by using some secret substance with the cement during the process of manufacture, the chemical action taking place in such a way that it closes the pores in the concrete without injuring in any way the strength of the cement. Probably wax is introduced into the clinker during the process of manufacturing the cement.

Some proprietary compounds are sold in the form of a solution, to be added to the water used in mixing the concrete. These are various forms of metallic salts, such as chloride of lime and oil emulsions. Soap solutions are also employed for this purpose. In the case of the liquids, the waterproofing property is imparted by the formation of gelatinous coatings about the minute particles of the concrete. Lime soaps, suspended in the water, are also employed (see page 432).

Selection of Proprietary Compounds.—In purchasing proprietary compounds, care must be taken to select such as have proved to be permanent in effect, as some of these compounds used for waterproofing purposes lose their effect after a few days' exposure to the weather and are entirely worthless. In the case of many so-called waterproof compounds of unspecified composition put together without regard to chemical principles, the effect upon the endurance of the concrete is absolutely unknown. In some cases they have been found to contain a large proportion of inert substances which interfere with the nominal setting of the concrete and materially decrease its strength while exerting a negative influence upon its permeability. Data in regard to the permanency and waterproof qualities

of these various proprietary compounds are not always available, and it will be necessary to use much care and judgment in selecting them, otherwise their use will prove a disappointment and a needless expense.

It is not proved that these proprietary compounds are any more effective than some of the means described at the beginning of this article for rendering concrete water-tight.

Inspection and Tests of Proprietary Compounds.—Proprietary compounds being usually purchased under trade names, and their composition being secret, there is little that the inspector is capable of doing in regard to them. He should, however, satisfy himself that the material specified is being used on the work, by identifying the packages, and noting that they are unbroken, and contain the proper trade-mark, in a manner similar to the inspection of cement (see Art. 2).

Where any expensive work is to be undertaken, and the employment of any of the proprietary compounds is contemplated, tests should be made to determine:

1. The effect on the strength of the concrete.
2. Their behavior when subjected to extreme ranges of temperature.
3. Their immunity to decomposition by various acids, etc., liable to reach the concrete.
4. The effect of admixture of the materials to steel, embedded in the concrete. In this connection see page 353.

Printed Directions to Be Followed.—When patented compounds are used, the inspector should see that the manufacturer's printed directions are followed, as much depends on experience to make a successful job. He should see that these directions are implicitly followed, and variations allowed only in case unforeseen conditions are encountered, and where special instructions to cover them are not at hand.

Work Being Done by Manufacturer.—When the work is being done by the manufacturer or his representative under a guarantee to secure water-tightness, the inspector should give the latter free rein to follow his own methods, providing they are in conformity with the general contract. He should, however, keep a complete and reliable record of the progress of the work for future reference. Very often patented compounds are not sold but are applied by the proprietors.

METALLIC STEARATES AND OTHER COMPOUNDS

Metallic Stearates.—Besides the materials mentioned above, various other chemicals are used to make concrete water-tight. One of the most successful of these is calcium stearate, which is a salt of a fatty acid. The metallic stearates act as void-fillers and in addition also possess in a marked degree the power to repel water. Some of the stearic compounds have been used in buildings that are now over ten years old, and as yet there is no symptom shown of a diminution in their water-repelling property. When first introduced it was feared

that they would seriously injure the strength of the concrete, but experience has proved that this apprehension was groundless. Metallic stearate is the base of many well-known proprietary compounds, which are usually bought under trade names.

Usually the quantity of finely ground metallic stearate added to the cement to make the concrete water-tight is about 2 per cent of the weight of the cement.

Other Compounds.—Besides the metallic stearates, other substances are used to make concrete water-tight; but none of them is as cheap or as effective as those mentioned above. Among these are: Japan wax, paraffine, resin, and oil emulsion. Alum alone, or aluminum alone, may be used, but it is much cheaper to use soap in connection with them, as mentioned on page 431. Among others, silicate of soda, commonly known as water glass, has been used. This material, however, tends to decrease the strength of the concrete—in some instances as much as 50 per cent. A mixture of oil and water has been used with fairly good success.

Alum and lye are sometimes used; but the author does not recommend the use of lye. Cement is sometimes destroyed by contact with alkaline water, and therefore the lye may injure the cement. However, if lye is used, care must be taken not to have an excess. A slight excess of alum does not decrease the strength of the cement mortar or concrete, but an excess of lye does.

PROPORTIONING, MIXING AND PLACING CONCRETE

Whatever ingredient is added to concrete to render it impermeable to water, it should be uniformly incorporated; and the concrete should be of a plastic consistency, and should be thoroughly mixed, carefully placed, and thoroughly tamped. In other words, reliance must be placed rather on careful proportioning, thorough mixing, and adequate placing than on the addition of any ingredient to overcome the result of neglecting these elementary principles of concrete manufacture. The essential requirements for successful waterproofing concrete work by the introduction of foreign ingredients are:

1. Homogeneity of Mixture.
2. Continuity of Work.
3. Soundness or Freedom from Cracks, etc.

Proportioning Concrete.—The proportions of waterproofing materials must vary to suit the character of the work and the requirements which the concrete must meet. The principal advantage of introducing waterproofing ingredients into concrete is to permit the use of a lean mixture, the fine particles of whatever ingredient is used tending to reduce the volume of the voids. Every case must be studied by itself, since it is frequently cheaper to obtain the required water-tightness by using extra cement than by admixtures (see Art. 47).

Mixing Waterproofing Ingredient.—Success in the use of any proper waterproofing ingredient always depends upon the thoroughness with which it is incorporated into the concrete. Even distribu-

tion throughout the mass is absolutely necessary. The inspector should see that the waterproofing material is uniformly distributed throughout the concrete. Irregular distribution will result in weak spots, which must be avoided as much as possible.

A proprietary compound in powder form should be added dry to the cement in the proportion specified by the manufacturer and the two thoroughly mixed until a uniform mixture is obtained. Under no circumstances should the compound be added after the cement has partially set or has been mixed with sand. The sand should be slightly moistened before mixing with the cement.

The concrete should be made wet (see page 186).

Placing Concrete.—All the concrete should be placed in one continuous operation (see page 290), each pouring being thoroughly spaded to insure uniform density. Great care must be taken in placing the concrete so that maximum density will be secured. In this connection see Art. 41, page 384.

Bonding New to Old Concrete.—Great care must be exercised in bonding old and new work. In fact, one of the difficult problems to be encountered in this work is the bonding of old to new concrete. In cases where joints are absolutely unavoidable, care must be taken to clean and roughen the old surface and have it thoroughly wet and slush-coated immediately before placing additional concrete. If so required by the engineer, the surfaces of the concrete already set should be thoroughly washed with material prepared for such purposes. A mixture of common muriatic acid and water in the proportion of one acid to three of water may be used to clean the old surface of the joint, which should be followed by a thorough washing with water to remove the acid. No concrete should be placed upon the old concrete thus treated until a competent inspector has passed on its condition, after which the new concrete may be laid. For methods of bonding new to old concrete, see Art. 27, page 327.

Soundness, Freedom from Cracks, Etc.—These should be minimized by the use of expansion joints (see Art. 28) and reinforcements. That is to say, by the introduction of steel or the use of some other precaution to prevent cracks in the concrete after it has set. The inspector should be particularly careful that the plans are properly carried out in this respect.

Art. 49. Special Treatment of Surface.—Coating Surface

Various methods of treating the surface of concrete have been employed to increase the water-tightness. Long continued troweling will produce a dense condition such as is found in concrete floors and sidewalks, which is practically impervious to water. This method of treatment has already been mentioned on page 426. Under the head of coating surfaces will be discussed all waterproof coatings applied to the surface of the concrete after it has set. Such coatings range from a wash to a plaster.

All methods of surface treatment with waterproof coatings have

the disadvantage that they prevent further hardening of the concrete as soon as they are installed, because no more moisture can penetrate to the interior, and it is moisture which is essential to further hardening. All waterproof coatings are rendered worthless by any minute crack in the concrete.

Waterproof Washes and Coatings.—The materials employed as surface coatings may be grouped in the following classes:

1. Alum and soap mixtures applied in alternate coats, popularly known as the "Sylvester" process (see page 437), and alum, lye and cement washes (see page 438).
2. Cement grout, with or without the addition of water-repellents (see page 439).
3. Miscellaneous materials of unknown composition. A large proportion of these are made from secret formulas and sold under trade names (see pages 440 and 441).
4. Paraffine and other mineral bases, applied cold in solution or prepared in melted condition (see page 442).
5. Waterproof cement mortar coating (see page 442).
6. Specially prepared bituminous products (see page 446).

All of the above, except classes 5 and 6, are applied to the surfaces directly exposed to the action of water. In the case of classes 5 and 6 the application is made to the inner surface of exposed building walls, their function in this position being not only to dampproof but to serve as an insulating film against rapid changes of temperature; and in the case of class 6 to replace furring and lathing, as plaster may be directly applied thereon.

ALUM AND SOAP WASHES—SYLVESTER PROCESS

The application of alternate coatings of soap and alum solutions is probably the most effective method of rendering set concrete waterproof. This is the well-known Sylvester method of making concrete impervious to water (see also page 431), and is applicable not only to concrete but to brick and stone masonry surfaces. The alum and soap penetrate the pores of the masonry, forming insoluble compounds due to chemical action between the alum and soap solutions, which prevents percolation. The application of the process gives the concrete surface a uniform color and generally improves the appearance. This process has been principally employed and is mainly adapted to coating the surfaces of tanks, conduits and other water-carrying structures, to render them tight. It has also been employed for treating concrete roofs and walls with varying success, and for removing efflorescence (see page 347).

The use of soap solution in connection with alum is one of the oldest waterproofing methods. The use of soap alone is more recent and less frequently used. The value of the soap alone is also rather doubtful, since it is soluble in water and may easily wash away if used as a coating before reacting with the concrete to form insoluble soaps. This latter is accomplished almost immediately in the soap-alum process on adding the alum wash.

Proportions.—The proportions generally used are three-quarters (3/4) of a pound of soap to one (1) gallon of water, and two (2) ounces of alum to one (1) gallon of water, both substances to be perfectly dissolved in water before using. The proportions of the solutions used in practice vary. Prof. Ira O. Baker in his book on "Masonry Construction," 1909 edition, states that the soap solution is made by dissolving 2.2 lbs. of hard soap per gallon of water, and the alum solution by dissolving 1 lb. of alum per gallon of water. The proportions first stated may be varied if better results are thereby secured.

Mixing Alum and Soap Solution.—The soap and alum must each be perfectly dissolved before using (see page 432).

Application of Coatings.—The concrete surface should be clean and dry before applying any of the washes (see page 448), and the temperature of the air should not be less than 50° F. at the time of application of the washes.

Both solutions should be applied with a soft, flat brush, the soap solution boiling hot, and the alum solution at 60° to 70° F. The soap solution is applied first, and should remain on twenty-four (24) hours, or until it is dry and hard, before applying the alum solution. Second coat should remain twenty-four (24) hours before the third coat (soap solution) is put on. In other words, one wash should be put on and allowed to dry—usually for 24 hours—when the other is applied. This constitutes one treatment, and as many treatments may be given as necessary.

The solutions should be well rubbed in, but care must be taken to avoid frothing in applying the soap wash. Two soft, flat brushes should be used, one for each solution.

On floor work the mixture can be poured on and swept over the floor with a broom until the concrete has absorbed all it will.

Number of Washes or Treatments.—Two or more washes of each solution should be applied, depending upon exposure, pressure, strength of solutions, and other local conditions. Two washes of each solution are said to be impervious to a head of 45 ft. of water, when mixed in the proportions first stated above. In some cases as many as six treatments have been employed. Professor Baker states in his book on "Masonry Construction" that eight washes of each solution in the second proportions stated above have made leaky concrete impervious under a head of 100 ft.

Aluminum Sulphate and Soap Washes.—Instead of using alum and soap as above, it is generally cheaper and more effective to substitute aluminum sulphate for the alum.

Alum and Lye Washes.—A wash consisting of 5 lbs. of alum dissolved in 2 gals. of water, to which 1 lb. of concentrated lye has been added, has been successfully used on green concrete surfaces.

ALUM, LYE AND CEMENT WASHES

A wash composed of alum, lye and Portland cement has been used for making a water-tight lining for tanks and cisterns. The action of the wash is to form an insoluble compound with the sulphate

of magnesia and other soluble salts, thus forming an impervious skin over the surface of the masonry, making an excellent waterproof coating.

Proportions.—A stock solution is prepared of 1 lb. of concentrated lye and 5 lbs. of powdered alum dissolved in 2 gals. of water. One pint of this solution is stirred in a 12-gal. pail containing about 10 lbs. of Portland cement, with enough water added to well fill the bucket. The cement should preferably be of a dark color, because the result wash bleaches somewhat. Where a 1:2 facing mixture is used on the concrete (see page 385), a 1 part stock to about 30 parts water will give good results.

Mixing Alum, Lye and Cement Wash.—Care must be taken to have every particle of alum and lye dissolved in the water used for the stock solution. Heating to near the boiling point will quickly insure this without injury to the mixture. After the addition of 10 lbs. of Portland cement to 1 pint of the stock solution, enough water must be added to insure the mixture spreading easily and working well on the surface to be treated with a calcimine or whitewash brush, filling all the pores. The mixture will be found to be satisfactory when it lathers freely under the brush. The solution must be kept well stirred after the cement is added.

Application of Wash.—Much depends upon the condition of the surface to be coated with an alum, lye and cement wash. If the surfaces are too dry, they must be well sprinkled with a hose just ahead of the waterproofing wash. The wash should be applied while the concrete is still green, or within three or four days after placing. The wash should be applied on a cloudy day, or while the concrete is protected from the sun, and while it is still moist; otherwise, too rapid evaporation on the water in the wash will leave the cement without the necessary moisture to set and leave it so that it can be brushed off. Additional coats can be given on successive days. The wash should be applied as soon as practicable without running, rubbing it well into the surface with the brush. If the wash is applied too thick it is liable to peel off. In a few hours the wash will withstand a water spray. If successive coats are properly applied, the resultant surface ought not to crack or peel.

This method is not satisfactory for application on old work. It may, however, be applied. In such cases, if the surface is dry, it must be thoroughly wetted with a spray or brush before applying the mixture.

CEMENT GROUT WASHES AND COMPOUNDS

Plain cement grout has often been employed for a waterproof coating, but owing to the fact that such coatings will absorb water by capillarity, and also on account of the difficulty of making such coatings adhere without peeling, they are not to be highly recommended. However, Portland cement grout is preferable to plaster (see page 410) for coating concrete wall surfaces. In fact, a thin mixture of neat cement spread on with a whitewash brush is quite effective, if thoroughly rubbed in.

Several prepared cement grouts are on the market which have been treated with water-repellents, and, having high penetrating qualities, they assist the bonding to the concrete surfaces. They are sold under trade names and are employed to impart a flat finish in various colors to concrete surfaces (see page 409), as well as to dampproof.

Application of Grout Wash.—The surface should be clean and well wetted with water before applying the wash (see page 448). The grout should serve only to fill the small pits and pores in the concrete surface. Care must be taken to see that the workmen do not get a coat of the grout on similar to a skim coat of plaster, as that is liable to peel in cold weather. In this connection, see page 406.

Two coats of ordinary cement grout wash will generally make ordinary concrete impermeable under a 10-ft. head of water.

The grout wash is most effective if put upon the water side of the concrete; if the wall is to be made impervious in both directions, both sides should be washed.

PROPRIETARY WATERPROOF PAINTS

There are many patented waterproof paints on the market that may be used to paint concrete surfaces. It is impossible to give a complete list of all of them, however, as new ones are being continually manufactured.

Attempts have been made to make special cement paints. One of them put on the market was purported to be a synthetic tri-calcium silicate. This same pigment also contained 50 per cent lithopone. Others have added Portland cement to varnishes and placed them on the market, but these decompose so quickly, the oil reacting with the cement, that they were withdrawn.

Selection of Proprietary Paints.—In purchasing proprietary waterproof paints care must be taken to select such as have proved to be permanent in effect, as very few of them are effective for long periods, because the majority contain oils of some nature which are attacked by the alkali in the cement with the production of soluble soaps. These are washed away with every rainstorm and the surface soon becomes non-waterproof. Data in regard to the permanency and waterproof qualities of these various proprietary paints are not always available. and it will be necessary to use much care and judgment in selecting them, otherwise their use will prove a disappointment and a needless expense. In other words, care must be taken in accepting these waterproofing paints without full knowledge of their nature and effect.

In this connection, see inspection and tests of proprietary compounds, on page 434.

Application of Proprietary Paints.—The composition of these proprietary paints is generally secret, and when they are employed the inspector should follow the directions of the manufacturer (see page 434). He should, however, see that in any case at least two coats of any material are applied. It is almost impossible to obtain

a surface free from pinholes and other defects on the first application. For condition of concrete surfaces, see page 448.

A wall that is full of dampness should never be painted on the outside and inside as well, as in that case the dampness is confined in the wall, with no means to escape, and will always dry out towards the heat, thus forcing off *any* paint which may be applied to that side. An opportunity for the dampness to dry out from a saturated wall must always be given.

MISCELLANEOUS PAINTS AND WASHES

There are several other materials that have been used as a wash for rendering concrete water-tight, but none of them is as cheap or as effective as the alum and soap or as the grout wash mentioned above. Among these are alum alone, aluminum sulphate alone, wax, paraffine, resin, stearic acid, and oil emulsion.

Use of Linseed Oil Paint.—Coating the surface with ordinary linseed oil paint until the paint ceases to be absorbed is sometimes used. There are two difficulties encountered in using an oil of this nature on concrete. First, linseed oil is an unstable compound, and does not have a very long life. Again, the oil coming in contact with the cement produces a soap which is soluble in water and is soon washed off.

Linseed oil paints must not be applied directly to new concrete, or to any concrete which has not been long exposed to the weather. The free lime in concrete not thoroughly weathered out by exposure to the elements will saponify the oil, destroy its adhesive power and its life, and the paint will soon scale off. After concrete has been exposed for a long time to the elements, linseed oil paint may be used with greater safety. It is difficult, however, to determine when the concrete is sufficiently free from lime to render it safe for the application of linseed oil paints, and it is therefore safer to avoid their use directly on concrete. In this connection, see page 409.

Use of Silicate of Soda.—Silicate of soda (liquid or soluble glass) is used to some extent for making concrete building blocks waterproof (see Art. 55). It answers the purpose very well, but is more expensive than the alum and soap or grout washes.

A solution is made with water, so strong that the water takes up all of the chemical that it will absorb. This solution is applied to the surface with a brush and well rubbed in.

Use of Silicate of Soda and Potash.—A wash of silicate of soda and potash mixed in about 10 parts of water is sometimes used to render set concrete water-tight. The concrete should be free from all moisture before the wash is applied.

Use of Liquid Hydrocarbons.—There are two kinds of compounds in this class—the first is a solution of paraffine in benzine and benzol. This kind of a material has been used for a long period and has many advocates. It is readily applied to a dry wall; to a wet one it will not adhere, consequently it can not be used to stop the flow of water through a pervious wall.

The second compound is an emulsion of a petroleum oil and fat oil, with water secured by means of the use of a little ammonia. The petroleum oil would naturally render the wall water-repellent and the fat oil might form a soap in the concrete which would fill the voids. The ammonia would soon volatilize.

Both compounds are of such a nature that they do not penetrate the mass very far and are only very superficial. The non-volatile part of one of them is paraffine as mentioned, which is inert, and in the other it is largely a petroleum oil, which remains unacted upon and under a slight head of water would be forced out.

PARAFFINE PROCESS

There are now on the market solutions of paraffine which are applied with a brush and close the surface pores of concrete, thus preventing absorption of water and efflorescence (see Art. 31). Pure paraffine wax installed with the application of heat is doubtless the most effective method of preventing ingress of moisture. In fact, it is one of the most durable of all the waterproofing methods for work exposed to the weather and for preservation of building stones. Instead of applying paraffine while hot, it may be dissolved in some volatile carrier, such as benzine, the carrier evaporating and leaving the paraffine to fill the pores in the surfaces of the wall. The paraffine should be specially hardened to resist the sun's action. Paraffine will resist the action of acids and alkalis.

Condition of Surface.—The concrete surface on which the paraffine is to be applied should be smooth and free from all projections. Holes should be filled up (see Art. 30). Surface to be clean and thoroughly dry, not only on surface, but all the way in. In fact, it is better to warm the surface with a torch if possible.

Application of Paraffine.—The paraffine should be heated and then applied with a brush, or if required by the engineer the surface should first be treated with artificial heat and, when sufficiently warm, melted hot paraffine wax applied thoroughly, well rubbed in, filling all corners, recesses, etc.

At least two coats should be used when the paraffine is applied cold, and in severely exposed locations three coats are advisable. If the carrier is inflammable, care must be taken in using it. Fire should be kept away from the material during application.

Care must be taken to avoid an excessive use of paraffine, which would give a glossy, oily appearance to the surface.

The hot paraffine should be applied by those specially equipped for and experienced in this kind of work. The workmen should at all times be under intelligent supervision.

WATERPROOF CEMENT MORTAR COATING

One method of waterproofing concrete that is popular is to coat the surface of the concrete with an impervious cement mortar coating. Sometimes this coating is simply a rich, dense cement mortar (see page 425), sometimes it contains a waterproofing compound similar

to those mentioned in Art. 48, and sometimes a special waterproof cement is used (see page 433). Rich cement mortar mixtures offer considerable resistance to penetration by water, and when well made may be used with a fair degree of success to waterproof ordinary concrete. A rich mortar plaster will reduce leakage, and may prevent it entirely, but it is questionable how far it will prove water-tight. A mortar plaster, however, may be made waterproof by the use of the alum or soap mixture or some of the proprietary compounds.

There are certain features that must be carefully considered in waterproofing by means of a cement mortar coating: (1) The inspector must satisfy himself that the wall upon which the cement mortar coating is to be placed will not crack; (2) the cement coating itself must contain a proper mixture of reliable waterproofing materials; (3) the greatest care must be exercised in mixing the waterproofed cement mortar coating; (4) the coating must adhere strongly to the concrete wall; (5) the fundamental principle of complete continuity must be rigidly enforced; and (6) the cement mortar coating carefully protected while it is setting. All this requires assiduous, painstaking work. When properly done, however, it repays the care exercised.

Proportions of Plaster Coat.—The proportions of the plaster coat are usually 1 part of Portland cement to 2 or 3 parts of clean, coarse sand. (See page 412.)

Sylvester Mortar Coatings.—In this class of coatings the alum and soap are added to the mortar, which is used as a plaster. To 1 part Portland cement and 2 parts sand add 3/4 lb. of pulverized alum for each cubic foot of sand and mix these ingredients dry; then add the proper amount of water, in which has been dissolved 3/4 lb. of hard soap to the gallon. The mortar must be mixed thoroughly.

Another recipe for such a mortar is given as follows: Powdered alum (1 per cent by weight) is thoroughly mixed with the dry cement and sand, and about 1 per cent of any potash soap (such as ordinary soft soap) is dissolved in the water used in mixing the mortar. The mortar must be thoroughly mixed.

Proprietary Compound Mortar Coatings.—To each bag of cement add dry the waterproof compound called for in specifications, in percentage directed by the manufacturer. Manipulate until the appearance and color indicate that a uniform mixture has been obtained. Mix the cement thus waterproofed with sand in the proportion of 1 cement to 2 sand (or other proportions, as may be required by the specifications). Sand is to be absolutely clean and well graded from coarse to fine. Sand need not be sharp (see Art. 8). Sand is to be moistened, waterproof cement spread over it, and the whole manipulated until a homogeneous waterproof coating is obtained. In this connection, see page 435.

Thickness of Plaster Coat.—It is usual to apply a continuous coat, 5/8 in. thick, of waterproofed cement mortar plaster to vertical surfaces, and the same plaster 1 to 2 in. thick on floors.

Preparation of Surface.—The difficulty with this method of waterproofing is to make the plaster stick. The surfaces must be thoroughly

cleaned and roughened by steel brushes, or equivalent, before the coating is applied. Most failures with plastering occur because the surface is not absolutely clean. The plaster can usually be made to adhere if the concrete wall is thoroughly and repeatedly washed with water; but if the wall has a dense, hard surface of nearly neat cement, it may be necessary to chip and wire-broom the surface to remove the skin or glaze, or apply a solution of ordinary muriatic acid in water to dissolve out the cement and roughen the surface (see page 328), followed by a thorough washing with clean water to remove all traces of the acid. A coat of ordinary whitewash, or a layer of laitance (see Art. 31), or an almost invisible film of the oil or grease used in oiling forms (see Art. 18, page 241), will keep the plastering from adhering unless they are carelessly removed. In this connection, see page 410. No plaster should be placed on the walls thus treated until a competent inspector has passed on its condition.

When the surface has been properly prepared the adhesion is so strong that the plaster can only with the greatest difficulty be separated from the wall.

Drenching Surfaces.—Just before the main mortar coating is to be applied, the properly prepared walls should be thoroughly drenched and soaked with water to its full absorbing capacity.

Slush Coating.—Before the wall shows marked signs of drying, a "slush coating" should be applied. To prepare this, some of the mixed, ready-for-use coating may be thinned with water to the consistency of thick cream, or a coat of cement grout may be used. The slush coating may be applied with a palmetto or with an equally strong-fibered scrub brush, with a scouring effect, care being exercised to fully cover in this manner the inner surfaces of all crevices and holes. It must be rubbed well into the surface.

The cement may be sprinkled on the surface, instead of being applied as a grout. The neat cement will make a firm joint between the wall and plastering. The plaster must be applied immediately after the neat cement has been dusted or painted on. If the neat cement is used as a paint it must be freshly mixed in small quantities every few minutes and followed by the plaster before it has set.

This slush coating may be made by a thorough mixing of waterproofed cement in water to the consistency of cream, instead of using ordinary cement grout.

Sometimes the surface is covered with a coat of tar, and while the tar is still tacky the plaster is put on. The tar should be mixed thick by boiling and should be applied very hot. It will then adhere to a very smooth surface. The tar could be used alone if it were not for its color and if it did not become brittle by oxidation. The tar must possess a high degree of elasticity and durability, and must have a gripping power so that plaster can be directly applied thereon. Tar specially prepared for this purpose may be easily obtained ready for use under various trade names.

Scratch Coat.—Before the slush coating has dried, or while the tar is still tacky, the first application of the regularly mixed water-

proofed coating should be applied as a scratch coat, 1/4 to 3/8 in. thick (usually 1/4 in. thick), and pressure brought on the trowel to push the coating on, to form a uniform bearing. The scratch coat should be troweled with considerable pressure, and to a fairly good surface, and scratched before hardening.

Finishing Coat.—Upon the scratch coat, before its final setting, the finishing coat of sufficient thickness to obtain a total thickness of, say, 5/8 in. should be applied. The finishing coat should be pushed on hard and uniformly troweled and floated to a true surface, free from pits, pinholes, sagging cracks, projections, or other defects. The floating of the finished surface should be done from the bottom of the wall up. In this connection, see also Art. 51, page 484. Special care must be exercised to apply this finish coat before the first coat has reached its final set. Several succeeding coats may be applied instead of one, until the desired thickness of mortar has been secured.

The composition of the finish coat as well as that of the scratch coat should be 1 part waterproofed cement to 2 parts sand, well graded and previously moistened, as mentioned on page 443.

Applying Finishing Coat After Scratch Coat Has Set.—Should there be cause at any time to prevent applying the finishing coat before the scratch coat has already set, then the latter should be thoroughly rinsed and slush-coated before the finishing coat is applied. (See pages 327 and 483.)

Removing Coating Which Has Become Set.—Any portion of the coating which should become set before it has been properly floated and finished should be entirely removed by chipping, and replaced with freshly mixed coating in the manner described above.

Joining One Day's Work to Another.—The joining of one day's work to a previously applied and hard-set coating should be straight edges, cut at the time when the older work is being finished. To make the joining the edge should first be scraped with the edge of a trowel or scraper; slush-coating should then be scrubbed into this edge, and fresh, regularly mixed waterproof coating should be hard rubbed, back and forth, under the nose of a pointed trowel, into the preceding slush coat. This point should again be well packed when the floating and the finishing troweling take place. In all cases, a continuous seal must be obtained.

Protection of Finishing Coat.—The finishing coat should be kept moist, by spraying or otherwise, and protected from sun and frost while it is in the process of setting (see pages 335 and 460). If the wall is under water the pressure should be relieved by drainage or by pumping until the plaster has set. In other words, an adequate drainage system, including an emergency sump, should be provided.

Test for Soundness.—When the work has thoroughly hardened (three to five days being allowed therefor), sounding with a light hammer over the wall should be resorted to by the inspector, to discover any loose or hollow portions. Any hollow or shelly places thus revealed should be entirely cut out with sharp steel points and replaced in the same manner as above described. The bond of the coating to floor or wall should at every point of contact be firm and

sound. For methods of patching and repairing defective surfaces, see Art. 30, page 338.

ASPHALT COATING—BITUMINOUS PROCESS

Asphalt is extensively used for dampproofing exposed buildings of superstructures by application to the interior of such walls; for underground work, to prevent absorption of ground dampness; and also for coating the covered faces of building stones to prevent staining and discoloration due to leaching of salts from masonry backing (see Art. 31). Several coatings are usually employed. The asphalt may be used alone or in combination with felt or other fabric, as mentioned in Art. 50, being applied to the surface or between two sections or layers of the concrete structure. The method of applying the asphalt directly to the concrete surface will now be considered.

In dampproofing exposed walls of buildings by application of an asphaltic coating on the interior surface of the walls, inspection should be particularly rigid, as failure means the removal of the plaster covering. Furthermore, the difficulty in tracing sources of leakage when the waterproofing is covered up makes the repair work more uncertain and costly. No special expert knowledge is needed for its application. Some judgment, however, must be used in selecting the asphalt to be used for waterproofing purposes.

Composition of Asphalt.—Asphalt should be of the best grade, free from coal tar or coal tar products. It must not volatilize more than one-half of 1 per cent under a temperature of 300° F. for 10 hours. It should not be affected by 20 per cent solution of ammonia, 35 per cent solution of hydrochloric acid, 25 per cent solution of sulphuric acid, nor by a saturated solution of sodium chloride. Asphalt should show no hydrolithic decomposition when subjected for a period of 10 hours to hourly immersion in water with alternate drying by warm air currents.

Range of Temperature.—Where asphalt coatings are used on surfaces exposed to the sun and frost, attention must be given to the fact that a compound of different properties is required where the range of temperature is great than where this range is smaller. For example, asphalt should have a flow point of 212° F. and a brittle point of 0° F. when exposed directly to sun and frost, as compared with, say, a flow point of 185° F. and a brittle point of 0° F. when covered from the direct action of sun and frost. (See also page 454.)

Condition of Surface.—All surfaces to be waterproofed must be in a condition fit to receive the same, namely, clean and dry.

Preparing Metal Surface.—Before applying asphalt to a metal surface, the metal should be cleaned of all rust, loose scale and dirt, and, if previously coated with oil, must be burned off with benzine or other suitable means. The metal surface must be warm to enable the asphalt to adhere to it, and the warming is best accomplished by covering it with heated sand, which should be swept back as the hot asphalt is applied. (See page 356.)

Preparing Concrete Surface.—The concrete surface must be

properly prepared to receive the asphalt coating, or else it will peel off. The asphalt must be applied when the surface of the concrete adjacent to it is dry—not superficially dry, but when the concrete is thoroughly set and the wall is dry for several inches in from the surface. Even then it is very difficult to make hot asphalt adhere to a concrete surface, however dry the same may be, unless it is heated by artificial means. Hot asphalt laid on ordinary dry concrete will not adhere and can be rolled up like a blanket after it is cool. By heating the surface of the concrete with hot sand before applying the asphalt, the latter may be caused to adhere to the same. If the concrete surface cannot be made dry and warm it should be first coated with asphalt reduced with naphtha or with some other asphalt paint, applied cold. It will generally be found preferable to use the asphalt cut with naphtha, applying it as a painting or swabbing coat. This is particularly necessary for vertical surfaces.

It is difficult to make either cold or hot asphalt adhere to the surface of concrete or mortar when the latter is covered with a thin film or skin of cement. To overcome this the surface should be covered with a finishing coat of mortar composed of one part of Portland cement to one or two parts of sand. If this is not permissible, the surface should be cleaned by chipping or with a sand-blast, in order to obtain a good bond.

No asphalt should be placed on the walls thus treated until a competent inspector has passed on its condition.

Preparing Asphalt.—The asphalt should be heated in a suitable kettle to a temperature not exceeding 450° F. Care must be taken not to prolong the heat to such an extent as to "pitch" the asphalt. Before the "pitching" point is reached the vapor from the kettle is of a bluish tinge, which changes to a yellowship tinge after the danger point is past. If this occurs, the material should be tempered by the addition of fresh asphalt. In case it should become necessary to hold the kettle for any length of time, a quantity of fresh asphalt should be put into the kettle and the fire banked or drawn. The asphalt has been cooked sufficiently when a piece of clean wood can be put in and withdrawn, the asphalt clinging to it. (See page 457.)

Application of Asphalt.—The first coat should consist of a thin layer of hot asphalt thoroughly mopped over the prepared surface.

The second coat should consist of a mixture of clean sand or limestone screenings, and asphalt, in the proportions of one part asphalt to three or four parts of dried sand or screenings by volume. This coat should be thoroughly mixed in the kettle and then spread on the surface (or first coat) with warm smoothing irons, such as are used in laying asphalt streets, and thoroughly tamped and pressed into place. The irons must not be hot enough to burn the asphalt.

The finishing coat should consist of pure hot asphalt spread thinly and evenly over the entire surface, and sprinkled with washed roofing gravel, torpedo sand, or stone screenings, to harden the top, especially when the coating is to be covered with earth or broken stone, so that the asphalt coating will not be damaged.

The first coat should be allowed to set up before the second coat

is applied. Coatings should be well rubbed in in corners and recesses and should be continuous throughout.

Thickness of Coating.—The entire coating should not be less than ½ in. thick at the thinnest place. The thickness of the coating will depend upon the character of the work, and may vary from ½ to 2 in. If a very thick coat is placed on a vertical surface, heat is liable to make it run unless it is supported in some way.

PREPARATION OF SURFACE

Condition of Surfaces.—All surfaces, before the application of the waterproof coating, should be prepared by chipping off their entire skin, so that an entirely new surface is produced. The concrete surface should be thoroughly chipped (or wire-brushed) not more than two days prior to the application of the waterproof coating. Before applying the coating it is important that the surface be clean, free from foreign matter, and in most cases dry; and a competent inspector should oversee the conditions. In each case all loose dirt, shavings or foreign substance must be removed from the surface to be coated.

Where cement coatings are employed and the waterproofing depends upon the setting of the cement, the surfaces should be *damp or wet,* so that the water necessary for the setting will not be absorbed by the concrete. Where the waterproofing depends upon the penetration of the material into the pores, the surfaces should be *dry,* to increase the penetration as much as possible.

Surfaces should generally be *smooth,* holes filled up, and projections removed. Projections are likely to be injured by scaffolding and to admit water at such points. Not only does a smooth surface make the application easier and more certain; it is also more economical in material. In the bituminous process (see page 446), however, where the material is applied on the inner surface of exposed walls and plaster is to be applied directly on the waterproof film, the surface should be *rough.* This is necessary in order that the plaster may properly bond to the treated surface.

The work should be done in dry weather when no water is entering, or the work properly drained until the coating has a chance to set and harden.

Facilitating Chipping of Surfaces.—The chipping (or wire-brooming) of surfaces may be facilitated by a previous application of common muriatic acid of, say, 1:10 solution, or a bonding compound, the strength of the solution depending upon the age of the wall (see page 328); or the use of the bonding material may be deferred until the chipping has been completed. Allow the acid to remain until it has exhausted itself, which will require at least ten minutes. A second liberal coat of acid solution should be applied before removing the first. A third coat should be supplied if the two applications have not satisfactorily exposed the aggregate and entirely removed the skin of hardened cement. Instead of using several coats

of the acid solution in the proportions given above, it may be made in proportions of 1 to 3 or 4, and only one coat used. (See page 339.)

Removal of Unspent Acid.—In case acid or bonding powders have been employed, all unspent acid should be removed by rigid application of the hose, immediately after the acid treatment has reached a satisfactory stage. Any remaining traces of acid may be detected by tasting the water left on the surface.

Brushing of the Chipped Surfaces.—The dust, dirt and loosened material must be completely removed from the chipped surfaces, either by scrubbing with stiff wire brushes, water nozzle under good pressure, steam jet, or other suitable means. An absolutely clean surface should be obtained not further ahead of the coating work than 24 hours.

Filling Voids.—All holes should be filled up—large holes with the waterproof concrete, and small holes with waterproof mortar. A perfect bond must at all points be secured with the underlying concrete. In this connection, see Art. 30, page 338.

WORKMANSHIP

Whatever method is employed for coating the concrete, the inspector should always see that the surface is properly prepared as described above. The essential requirements for good work are:

1. Homogeneity of mixture.
2. Continuity of work.
3. Soundness or freedom from cracks, etc.
4. Uniform and efficient bond of coating to concrete.

Homogeneity of Mixture.—The inspector should see that the waterproofing material is uniformly distributed throughout the coating that is to be applied. Irregular distribution will result in weak spots, which should be avoided as much as possible.

Continuity of Work.—The inspector should see that the application of the coating is continuous throughout and that all portions called for on the plans receive waterproofing treatment. Any omissions at corners, cornices, around windows and other points will break the continuity of the work and will nullify the object which the designer has endeavored to attain, and may prove fatal to the final success of the work. The surface should be gone over carefully and retouched where necessary, in order that the coating shall be uniform. A complete, unbroken film must entirely coat the surface to be covered, and this requirement is essential to success. Water and dampness will find their way through the smallest pinholes, therefore a thorough coating is required.

Soundness, Freedom from Cracks, Etc.—These should be minimized by the use of expansion joints and steel reinforcements. The inspector should be particularly careful that the plans are properly carried out in this respect.

Uniform and Efficient Bond.—The bond is an important matter where the waterproofing is done by the application of a coating to

the concrete surface. The coating should be homogeneous. continuous, sound, and uniform. A good bond will require:

1. Correct mixture of the coating materials.
2. Proper condition of surface to receive the coating.
3. Thoroughness in application.
4. Careful connection of one day's work to another.

Art. 50. Layers of Waterproofing Material—Membrane Method

This method of making concrete waterproof consists in surrounding the structure with an impervious shield, envelope or membrane which keeps the water away from the concrete. Strictly speaking, this is not a method of rendering concrete impervious.

DEFINITIONS AND FUNCTIONS OF MATERIALS USED

The common bituminous-membrane method consists in the use of a fabric (paper or felt) saturated with bituminous material and a bituminous binder.

Binder.—By a *binder,* as the word would imply, is meant a material that binds two surfaces together; that is, an adhesive material.

Bituminous Material.—By a *bituminous material* is meant any material containing a large proportion of solid or semi-solid bitumen, bitumen being that portion of *pitch* that is soluble in carbon bisulphide, benzol, petroleum, ether, or other similar solvent.

Pitch.—The exact meaning of the term *pitch* should be clearly understood, so as to remove some widespread misconceptions. Pitch is a general term, and it may be applied indiscriminately to coal tar (see page 453) and also to the resinous sap of pine trees, or to asphalt (see page 453). All kinds of pitch have in common the property of resisting the penetration of water, although in a greater or less degree, so that the name itself has become synonymous with the waterproofing quality.

Saturated Fabric.—As its name implies, *saturated fabric* is nothing more nor less than an absorbent fabric that has been passed througb a hot bath of liquid refined tar or prepared asphalt of such consistency as to penetrate its structure thoroughly, superfluous tar or asphalt being squeezed out between rollers. After this treatment the fabric is subjected to an aging process, which toughens it and makes it ready for use. The bituminous binder and the saturating material with which the fabric is prepared should be similar in character, in order that the union between the fabric and the pitch binder may be as intimate as possible.

Functions of the Fabric and Bituminous Binder.—The bituminous membrane is built up in place in successive layers consisting of several—usually four or more—thicknesses of waterproofed paper or felt, cemented together with tar or with asphalt, and should form, when finished, a practically homogeneous and continuous waterproof

envelope or shield. The functions of the saturated fabric (paper or felt) and bituminous binder should be clearly understood. The use of the fabric is to serve as a retainer of the pitch or bitumen; that is, the fabric serves to hold the bitumen (tar or asphalt) in place, while the latter is the waterproofing material.

Even though pitch or bitumen appears hard at ordinary temperatures, it is somewhat viscous and has the property of flowing under moderate but continued pressure. This tendency to flow is counteracted by using it in thin layers between successive courses of absorbent fabric. The pitch or bitumen penetrates the fabric and the fabric serves to hold the pitch or bitumen in place and to give strength, very much as does the hair used in mortar (see page 412). The fabric also enables the pitch or bitumen to resist ordinary pressure and to bridge small fissures caused by settlement. The fabric is therefore an essential part of the combination, but, as should be clearly understood, it is not in itself the waterproofing material, and must at all times be completely enclosed by an unbroken layer of pitch or bitumen. While the fabric is not in itself the waterproofing material, it must of itself be waterproof, so that each individual layer may serve as an independent barrier to the passage of water, while the intermediate coating of pitch or bitumen must individually supplement this waterproofing quality and collectively bind the series of plies into a pliable sheet of substantial thickness.

The particular attributes of a satisfactory pitch or bitumen are discussed on page 453, and of a suitable fabric on page 454.

SELECTION OF WATERPROOFING MATERIALS

It is imperative that no chances be taken in the selection of the bituminous binder and the waterproofed fabric, for the risk is too great—to make a bad job may entail an expense ten to twenty times their original first cost. Hence only the very best of materials should be employed.

Bituminous Binder.—The source of the pitch or bituminous binder is a question of great importance, because on its ability to resist the dissolving action of water rests the permanence of its waterproofing effect. In underground work the action of the water is sometimes made more difficult to resist because it contains sewage, drainage from manufacturing establishments, gas, liquor, etc., which have a solvent action on poor pitch or bitumen. On a roof, it is not only the dissolving action of water, but also the effects of sun and wind, heat and cold, that must be withstood. The corroding influence of these agencies is so strong that few materials can resist it for longer than a few years.

Coal-tar products deteriorate when exposed to moisture. Some asphalts are more suitable than others for waterproofing purposes; therefore the properties of any asphalt intended for waterproofing should be thoroughly investigated (see page 454).

Tar Paper.—Time was when so-called tar paper was the best and, in fact, practically the only material available for use in the then

undeveloped practice of waterproofing by the membrane method. Before the general advent of wood pulp even the paper used for building purposes was of good quality, with distinct fiber and reasonable strength. The coal tar used for saturation was likewise of far higher grade than is generally employed today. It is not strange, then, that work executed years ago with such relatively good materials should, where not exposed to unduly destructive agencies, be now and then found to be in good condition. It is this very fact, combined with lack of knowledge or progress in the science of waterproofing, that still leads some to employ the present-day materials which pass under the same name.

But tar paper (or even coal-tar felt) is today ordinarily a cheap material of little strength and less endurance under the searching requirements of modern waterproofing construction. The paper is usually of short fiber, hard and brittle. The coal tar used as a saturant has been refined to such a point in order to extract the various products which are more valuable for other purposes, that the coal tar left and used for saturation is practically nothing but a residuum of little value for any purpose. (See page 454.)

Burlap or Similar Woven Fabric.—Burlap or a similarly woven fabric is sometimes used with tar and asphalt to give them elasticity. Fundamentally the complete vegetable character of such material is objectionable, for it is possessed of little durability when exposed to underground conditions. The fact that it is woven still further contributes to its unworthiness; for, unlike a uniform fabric similar to felt, or even paper, its body consists of alternate material and interstices. If the asphalt or tar becomes cracked, such material offers no additional protection.

Waterproofing Felts.—Considerable attention should be given to the selection of a waterproofing felt, owing to the development of various fabrics universally called "waterproof felts," although possessed of that quality in various degrees. Waterproofness, pliability and durability are obviously the prime essentials in a good waterproofing felt. As in all materials, the quality of the finished product depends upon the individual qualities of its ingredients. The exacting demands made upon a waterproofing felt and its relative small cost as compared with the damage which may result from possible inferiority, make it imperative that only the very highest grade of materials should be used in its manufacture. But the quality of the ingredients, even though of the best, does not alone determine the real value and efficiency of the product when used for a specific purpose. Character and suitability in view of the conditions are of equal importance. (See page 454.)

SOURCES OF SUPPLY OF BITUMINOUS MATERIALS

The pitch binders, saturating and coating compounds generally used in bituminous waterproofing, are either coal tar or asphalt. The basis of either of these materials is bitumen (see page 450), and they differ from each other in the amount and character of the

other ingredients present, corresponding to the sources from which they are derived.

Varieties of Bitumen.—One of the groups of mineral substances composed of different hydrocarbons, which are widely scattered throughout the world, is known as bitumen (see page 450). There is a great variety of forms in which bitumen is found, ranging from volatile liquids to thick semi-fluids and solids. These are usually intermixed with different kinds of inorganic or organic matter, but are sometimes found in a free or pure state. Liquid varieties are known as *naphtha* and *petroleum;* the viscous or semi-fluid, as *maltha* or *mineral tar;* and the solids, as *asphalt* or *asphaltum.*

Asphalt.—*Asphalt,* or *asphaltum,* as it is sometimes called, is a natural bituminous material, as mentioned above, and is found in a more or less advanced state of distillation. The asphalt commonly used in America is obtained either from Trinidad or from Bermudez, where the most noted deposits are to be found. That obtained from the former place is known as *Trinidad pitch-lake asphalt,* and that from the latter place as *Venezuelan asphalt.* Deposits of nearly pure asphaltum are found in Utah, Mexico, Cuba, and different parts of the United States. Varieties of nearly pure asphalt are known as *wurtzilite, elaterite,* and *gilsonite.* Crude asphalt is put through a process of manufacture or refining before it is used for waterproofing purposes.

Coal Tar.—Coke is a fuel used largely in blast furnaces. It is made by heating soft coal. Coke bears the same relation to coal as charcoal does to wood. In the manufacture of coke, the heat drives gases out of the coal, and at the same time a black, viscous, bituminous material is obtained from the coal, leaving the coke. This material is *coal-tar,* used in manufacturing and waterproofing. The crude coal tar is put through a process of manufacture or refining before it is used for waterproofing purposes.

COMPOSITION OR PROPERTIES OF MATERIALS

Layers of waterproofing materials used in the membrane method range from ordinary tar paper laid with coal-tar pitch to asbestos or asphalted felt laid in asphalt.

Quality of Materials.—Both the cementing materials and the fabrics, in order to be serviceable for waterproofing operations, must be elastic and durable and retain these properties throughout the range of temperature to which they may possibly be subjected after being placed in the work.

Flowing Point of Bitumen or Pitch.—The relative low melting point will readily distinguish whether a coal tar is being substituted when asphalt is specified, and, in addition to the weight and flowing point, the characteristic odor of the tar will detect substitution.

Adulteration of the asphalts with cheaper petroleum products or other foreign brand, usually specified, will also make itself known in the lower flowing and lower flaming point, the petroleum oils decreasing these points in accordance with the amount present.

When bituminous products are specified and delivered under

trade names and are to be applied cold, the flowing point cannot be used as a factor so readily, but such material should also be tested for brittleness under low temperature, and stability at high temperature and acids tests should be made to determine their immunity from ready attack by acid present in the ground water.

Weight of Bituminous Materials.—The weight is also a distinguishing feature between coal-tar pitch and asphalt, and will aid the inspector in his work. Standard roofing coal-tar pitch weighs 11 lbs. to the gallon, or 180 gallons to the ton. A cement barrel of pitch weighs about 300 pounds. A good coal-tar pitch for waterproofing should weigh 70 to 80 lbs. and a good asphalt 90 to 95 lbs. per cubic foot.

Composition of Coal-Tar Pitch.—Soft coal-tar pitch should be used. It should be straight-run pitch, distilled directly from American coal tar, one which will soften at 70° F. and melt at 100° F., being a grade in which distillate oils, distilled therefrom, have a specific gravity of 1.105. If soft pitch is not obtainable, hard pitch may be used. Hard pitch may be made soft by adding dead oil in quantities not exceeding 1 of dead oil to 30 of hard pitch. Soft pitch, however, is more desirable.

Grade of Asphalt.—The asphalt used should be the best grade of Bermuda, Alcatraz, or lake asphalt, of equal quality.

Composition of Asphalt.—The following requirement for asphalt is that given in the specifications for the New York subway (Contract No. 2, June, 1902, page 107), approved by Mr. William Barclay Parsons, Chief Engineer:

"The asphalt shall be a natural asphalt or a mixture of natural asphalts, containing in its refined state not less than ninety-five (95) per cent of natural bitumen soluble in rectified carbon bisulphide or in chloroform. The remaining ingredients shall be such as not to exert an injurious effect on the work. Not less than two-thirds of the total bitumen shall be soluble in petroleum naphtha of seventy (70) degrees Baumé, or in acetone. The asphalt shall not lose more than four (4) per cent of its weight when maintained for ten (10) hours at a temperature of three hundred (300) degrees Fahrenheit."

Waterproofing Paper.—Tar paper is usually of short fiber, hard and brittle. The coal tar used as a saturant is sometimes refined to such a point in order to extract the various products which are more valuable for other purposes, that the coal tar left and used for saturation is practically nothing but a residuum of little value for any purpose. Tar paper should therefore be very carefully inspected before being used. To be efficient, a paper should not be temporarily waterproof, but permanently waterproof. The stock from which the paper is made must be good. No poor paper can permanently hold its waterproof qualities, for the waterproofing soon dies out, leaving a brittle and lifeless paper to crumble and rot away.

Waterproofing Felts.—Felt used in waterproofing should be composed of asbestos or other equally non-perishable material. Wool is invaluable in a waterproofing felt, because of its superiority to other available materials as an absorbent of the saturating compounds used.

Its percentage, therefore, determines the possible degree of saturation. The felt should contain an amount of wool equivalent to from a minimum of 20 to a maximum of about 30 per cent of the weight of the unsaturated fabric. A lesser amount would leave the felt inadequately waterproofed, while a greater amount would so increase the relative amount of saturated compound as to decrease the strength. In other words, the proportion of wool should average about 25 per cent. The balance should be made up of such material as will best serve in combination with the wool and the saturant to form the most pliable, durable and waterproof fabric.

The ash from the unsaturated felt should not exceed 5 per cent by weight.

Soapstone or other substance in the surface of the felt, to prevent adhesion, should not exceed ½ lb. per 100 square feet of felt.

The felt should be properly treated with pitch, asphaltum or other suitable material. The saturating and coating compounds should be of a character capable of remaining plastic after long heating (for at least 10 hours) at a temperature of 250° F. The coating must not crack when the felt is bent double at ordinary temperature.

The saturating and coating compounds used in the felt must not only serve specifically as insulation against moisture, but it must remain unaffected by combined contact with water or dampness, even at high or low temperatures. The saturant must not deteriorate with age and must be capable of resisting the chemical action of all ordinary agents which may be found in ground waters, escaping sewerage and the like, and permit the felt to remain permanently pliable. In its best form such a compound should be a combination of gums and mineral non-volatile oils insoluble in water. All injurious chemicals must be eliminated.

The felt should be capable of easy application, being soft, pliable, and tough when received from the factory and placed in the work. It should have a natural affinity for any mineral pitch, distillates of straight asphalt or straight coal tar, which may be employed for cementing the sheets of felt together in the process of applying the work.

The weight of the wool felt before saturation should be from 5 to 6 lbs. to the square of 100 ft. When saturated and coated one side with asphaltic products it should weigh, roughly, 12 to 14 lbs. per square of 100 ft., while the weight of a similar area saturated and coated on both sides should range from about 14 to over 16 lbs. Standard saturated felt is 32 in. wide and weighs from 60 to 65 lbs. to the roll.

The quotient obtained by dividing the tensile strength in pounds of a strip of asphaltic felt 1 in. wide, cut lengthwise, by the weight in pounds of 100 sq. ft. should not be less than 7.5.

The quotient obtained by dividing the tensile strength in pounds of a strip of asphaltic felt 1 in. wide, cut crosswise, by the weight in pounds of 100 sq. ft. should not be less than 3.75.

The strength saturated should be at least 25 per cent more than the strength unsaturated, taken lengthwise.

PREPARATION OF SURFACE

The preparation of the surface to be waterproofed so that it will be perfectly smooth is important. In this connection, see page 448.

Condition of Surfaces.—All surfaces to be waterproofed should be as smooth as possible and should be dry. All dirt and foreign matter should be removed before waterproofing is applied. Concrete must be allowed to thoroughly set, and all uneven surfaces level up with a coat of cement mortar (see Art. 30). The surfaces may be smoothed off with a trowel if too rough. No waterproofing should be placed on the surfaces thus treated until a competent inspector has passed on its condition. It is difficult to make a bituminous sheet adhere to a surface that is either too rough, too wet, covered with dirt or other foreign matter, or possessing too fine a glaze, due to richness of cement surface. Sharp projections on the masonry should be removed or they will puncture the waterproofing.

Application of Heat for Drying Surfaces.—In particular situations, where special difficulty is encountered in securing dryness on surfaces to be waterproofed, apparatus for local application of heat should be used if necessary to expedite drying of surfaces. The method to be pursued should be in accordance with most approved usage as applicable to the materials used. The concrete should have at least 48 hours to set before artificial heat is applied. (See page 354.)

Drainage System.—It is a difficult thing to place the material on a wall reeking with water. An adequate drainage system should be installed and maintained at all times, until the waterproofing is completed. It is absolutely necessary to keep down the water pressure. If this is not done the material is liable to be pressed off the wall before the supporting masonry is placed. In the floor, where necessary, sumps with drainage channels should be provided, so that water may be removed by pumping in advance of the waterproofing.

Additional Layer of Fabric.—If for any reason it is impracticable to have the concrete dry, then a layer of felt or treated fabric, in addition to those called for in the specifications, should first be laid against the surface, and on the upper surface of the felt, or treated fabric should be spread the first layer of pitch or asphaltum. This additional layer of felt or fabric should not be counted as one of the required layers or plies. Some specifications require that asphalt cut with naphtha shall first be applied cold instead of the additional layer of fabric.

Metal Surfaces.—Metal surfaces should be dry and clean, free from rust, loose scale and dirt. If previously coated with oil, same must be removed with benzine or other suitable means. Warming may be accomplished by heated sand (see page 356), which is removed as material is applied.

LAYING WATERPROOFING MATERIAL

The waterproof sheet should be applied continuously over the whole surface to be treated as shown on the plans; thus, in building structures it should be applied over all footings, walls, cellar **bottoms,**

and on the other face of all foundation walls. Lack of continuity will be fatal to any waterproofing work, as water is sure to find its way through any breaks, however small.

All surfaces to which waterproofing is to be applied should be made as smooth as possible. On these surfaces there should be spread either hot melted pitch or asphaltum (or other cementing material) in a thick layer of uniform thickness; on this layer of pitch or asphaltum should be laid the waterproofing fabric; this process should be repeated until such number of layers as may be required have been placed, and a final coat of pitch or asphaltum should then be applied. In the application of these materials certain fundamental requirements must be fulfilled upon which the final success of the work will largely depend, and it is the duty of the inspector to see that such requirements are fulfilled. These requirements may be conveniently classed under the following heads:

1. Preparation of surface (see page 456).
2. Continuity of work (see page 449).
3. Protection of waterproofing (see page 460).

Thorough inspection is particularly essential where the waterproofing is to be covered or backed up by protecting masonry or other material, and thus cannot be readily reached for repairs.

Joints.—The layers of fabric should not be laid independently but shingled on consecutively. All joints should be broken at least 4 in. on cross joints and 12 in. on longitudinal, and at least 18 in. lap left at corners to form good connections with adjoining sections. Special care must be taken that all joints are well broken and cemented together. A primary requirement with all waterproofing laid in layers of fabric is that the edges shall overlap so that as sheet after sheet is laid side by side these laps shall be uniform and the number of thicknesses be the same in all parts. The ends of the bottom layers must be carried up inside the layers on the sides, so as to insure a full lap.

Preparation of Asphalt.—Care must be taken that the asphalt is not "pitched." This will take place if heated about 450° F. The inspector can tell when this point is reached, by the change in color of the vapor from a bluish tinge to a yellowish tinge. The inspector can further test for the sufficiency of the cooking by putting in and withdrawing a stick of wood. The asphalt should cling to it. Should pitching occur, fresh material should at once be added to reduce the temperature. In case it should become necessary to hold the kettle for any length of time (or pitching is to be prevented), a quantity of fresh asphalt should be put into the kettle and the fire banked or drawn. The asphalt when applied should be at a temperature of not less than 250° F. (See page 447.)

Spreading Pitch or Asphalt.—Each layer of pitch or asphaltum must completely and entirely cover the surface on which it is spread, without cracks or blowholes or other imperfections. The compound should not be spread on for more than 9 sq. ft. of surface at a time; i. e., not more than 3 ft. in front of a roll of felt which is

36 in. wide. The mopping of the materials should be done quickly, uniformly and thoroughly while it is at the proper temperature.

For one square (100 sq. ft. or 10x10 ft.) of roof or horizontal waterproofing, about 40 lbs. of pitch should be used for each mopping, and for one square of wall or vertical waterproofing about 50 lbs. of pitch should be used for each mopping.

Laying Fabric.—The pitch or asphaltum (or other cementing material), thoroughly heated, should be applied with a mop on the prepared surface, and the fabric immediately rolled over the surface. Where it is possible, several rolls should be started at once and the cementing compound swabbed on the surface ahead so that there is the least possible loss of time in covering it with the fabric and pressing the same into position.

The first roll having been started and mopped, the second is placed so as to overlap the first by a width, depending upon the number of plies to be laid. For example, if the felt is 32 in. wide and is laid 3-ply, the second roll should be lapped upon the first about 22 in., or two-thirds of the width; or, if it is to be laid 6-ply, the lap of the second roll over the edge of the first should be about 26 in., or five-sixths of the width. As soon as the second roll has been sufficiently unrolled (in the same general direction as the first), the third roll should be started so as to lap both of the others. This process, with the corresponding mopping, should be continued for the entire width of the surface which is to be covered. The fabric in every case must be applied to the pitch while the latter is still hot, and it must be pressed against the pitch so as to insure its being completely stuck to the pitch over the entire surface.

In no part of the work should fabric touch fabric, but be cemented with pitch or asphaltum. In fact, a primary requirement with all waterproofing laid in layers of fabric is that these sheets as they are successively laid shall be securely cemented to each other, that there shall be no air pockets, causing separation of the sheets, and no uncoated surfaces, the spaces between which might furnish channels for the passage of water.

The sheets should be applied vertically to the wall surfaces, and these sheets should not be longer than can conveniently be handled.

In connecting side wall with floor work the layers of fabric on the sides should be carried down on the outside of the ends of the floor layer and a lap of at least 18 in. should be allowed for same. Especial care must be taken with this detail.

In connecting side wall and roof work the layers of fabric of the roof should be carried on the outside of the side wall layers and should lap at least 18 in. Especial care must also be taken with this detail.

All corners should be reinforced with two extra pieces of fabric snugly fitted into it, one between the second and third layers and one on top. The most difficult and important points encountered in waterproofing are the work of carrying the covering safely around corners and the turning of angles. In such places the fabric should be cut and fitted in small pieces, and a small hand mop should be

used, great care being taken to press the fabric into the hot tar or asphalt and to make sure that there is a perfect bond between them.

Carrying Waterproofing against Sheet Piling.—In case tongue-and-grooved sheet piling is used for making and protecting the excavation, and this piling has been treated with an efficient wood preservative, the waterproofing may be carried up against the sheet piling. The sheet piling should be given a thorough coat of hot pitch or asphaltum, and all joints thoroughly filled before the first layer of fabric is placed thereon. Coppered carbolineum or other wood preservative may be used for protecting the sheet piling.

Connecting New to Old Work.—One of the difficulties in securing continuity with layers of fabric is encountered in the joining of new work to old. The laps become covered with dirt, cement mortar, water, etc. Before new work is added to old, the joints should be thoroughly cleaned of all foreign matter, such as cement mortar, or other substance which finds its way thereon, and coated with the cementing material. It is here that a competent inspector is needed, as workmen are often tempted to neglect this precaution. The new fabric must be made to stick smoothly and evenly over the entire joint area.

Number of Plies.—The "ply" in waterproofing—that is, the number of layers which cover all parts of the surface—varies from 3-ply to 10-ply. Four or five layers are usually sufficient for ordinary cases, although from six to ten layers may be necessary for reservoirs and similar structures. The number of layers of fabric required depends upon the water pressure and the quality of the fabric. As many sheets or layers of fabric should be cemented or veneered together as the conditions require. The thickness of the damp, or waterproofing, course should be determined by the amount of dampness and the head of water to be excluded, as well as by the importance of the work, and should vary from a minimum of three plies of fabric and four moppings of pitch or asphaltum, where dampness of comparatively dry soil is to be excluded, up to a maximum of ten plies and eleven moppings where there is a considerable head of water to contend with. A good rule is to use five plies of fabric and six moppings of pitch or asphaltum for any actual head of water up to ten feet, and for every additional five feet of head add one ply of fabric and one mopping of pitch or asphaltum.

The inspector should be careful to observe that the number of plies or thicknesses called for in the plans and specifications is actually put into place.

Continuity of Work.—The inspector must see that all portions called for on the plans or in the specifications receive waterproofing treatment. Any omissions will break the continuity of the work and will nullify the object which the designer has endeavored to attain. (See page 449.)

Skilled Labor.—Every detail of the work requires careful attention, and unless men skilled in this work are employed materials may be wasted and be of no benefit. In other words, the waterproofing should be done only by experienced and expert laborers or

waterproofers. A serious mistake is sometimes made in attempting to do the work with incompetent and inexperienced men.

Freezing Weather.—No waterproofing should be done when the temperature is below 25° F. Good work cannot be done in very cold weather, as the air chills the bitumen too quickly.

Delivery of Materials.—The inspector should see that all the material delivered arrives in unbroken packages and contains the proper label of the manufacturers as specified.

Storage of Paper or Felt.—The rolls of paper or felt should be stored on end and not laid on the side.

PROTECTION OF WATERPROOFING

The application of the fabric and the pitch or asphaltum compound does not by any means complete the work. It is very important to carefully protect the waterproofing until it is completed and until the permanent protection is placed.

After the waterproofing has been put into place it should be properly protected against injury from any cause whatsoever, i.e.: backfilling with earth; depositing concrete against same; laying brickwork or rubble against same; bulging of waterproofing from wall; cracking of same due to bulging; running of material due to heat; injury due to frost; injury due to gas from street mains; throwing tools, bricks, or other débris thereon; and passing of men or wheelbarrows thereover.

Interruptions.—Owing to the necessity of carrying on the other parts of the work at the same time as the waterproofing, and to the need of storing materials, erecting derricks, etc., the work is liable to constant and vexatious interruptions. Under all such circumstances it must be constantly borne in mind that the finished work must at all times be protected from abrasion or blows until finally covered in by a safety coat of mortar or permanent masonry; also, that where work is left to which later work must be attached the laps necessary to make a good bond should invariably be left (see page 459) and properly protected.

Safety Coat of Mortar.—The layers of waterproofing fabric should be protected from injury by a layer of cement mortar (generally 1 in. thick) mixed in the proportion of 1 part Portland cement to 2 parts sand. This safety coat of mortar should be placed as soon as possible after the laying of the waterproofing, not exceeding 12 to 16 hours, or sooner if the engineer should so direct. Special care must be taken in laying the mortar not to break, tear or in any way injure the layers of waterproofing fabric. For methods of laying a plaster coating, see page 410.

Failure Due to Improper Safety Coat.—Should the waterproofing be injured owing to failure of placing the protective coat of cement mortar, which injury is caused by exposure to weather, bulging from masonry surface or puncturing from any cause, the contractor should be required to remedy the same at his own expense.

Placing Masonry against Waterproofing.—The placing of con-

crete, brick, stone or rubble masonry against the waterproofing must receive careful attention on the part of the inspector, especially when the safety coat is omitted. The greatest care must be exercised that the waterproofing sheet is not punctured by sharp corners of brick or stone. In other words, care must be taken not to break, tear or injure in any way the outer surface of the pitch or asphaltum. Innumerable good jobs have been injured and even ruined by being punctured during this operation, especially when the backing is concrete. Sharp projecting stones coming in contact with the outer surface of the pitch or asphaltum will break a hole through the latter which will admit water, making the source of such a leak extremely difficult to discover. It is always advisable where masonry comes in immediate contact with the waterproofing to protect the latter with a safety coat of cement mortar as mentioned above.

When brickwork is placed against waterproofing on vertical walls a slight space should be left for slushing in with mortar to avoid puncturing the outer surface of the pitch or asphaltum. The bricks should not be rammed up against the waterproofing sheet. It is advisable to use the safety coat as just mentioned.

Backfilling with Earth.—Protection of the waterproofing should not stop with placing the backfilling on or against same. Tamping against it should be forbidden, especially when the safety coat is omitted. The waterproofing may be protected by a 4-in. wall or by a concrete partition, instead of the safety coat of cement mortar. (See page 320.)

Water Pressure.—Where springs of considerable ground water are encountered, ingenuity must be exerted to keep the moisture or water pressure out until the waterproofing is in place and well supported; otherwise injury to the waterproofing might occur, especially when the water pressure is very large and insufficient weight has been placed upon same to secure it against displacement by such pressure. The water pressure should be relieved by draining, or by pumping if necessary. Sumps may sometimes be built below the floor level and the water allowed to run into them, being afterwards pumped out and the holes filled with a mass of concrete to resist the water pressure. An adequate drainage system, including an emergency sump, should always be provided for in the design.

Protection from Gas.—Care should be taken to prevent gas from coming in contact with the waterproofing. Asphaltic compounds have been seriously injured by gas escaping from the mains in the street.

Openings or Incisions in Waterproofing.—When openings or incisions in the waterproofing sheet are necessary, the inspector should see that such places are repaired in the most thorough manner.

Passages for Pipes, Etc.—Where a pipe has to run through the waterproofing fabric, as is the case with sewers, water pipes, etc., the fabric should be wound around the pipe with great care. The pipe must first be thoroughly cleaned off so that the pitch or asphaltum will stick to it, and then after the fabric has been wound around the pipe, one or two (preferably two) flat iron bands about

⅛ in. thick should be bolted very tightly around the seal. These flanges fit the pipe tightly and clamp the waterproofing fast between them. All inwardly projecting fabric should be cut off and the seal scraped clean so that concrete will adhere to it. If there is any pitch or asphaltum between the concrete and the pipe, the seal will probably flow and perhaps leak. All pipe passages should be neatly pocketed and connections thoroughly made. Such places should not be covered up until the work has been examined by the inspector and found properly executed.

Protection of Roof Waterproofing with Gravel or Slag.—In the case of a roof, the layers of fabric and pitch or asphaltum should be covered with a coat of gravel or slag embedded in pitch or asphaltum. This coating serves a double purpose, first, that of furnishing as large an amount of mineral surface to withstand the action of the elements as possible, and second, to stiffen mechanically the layer of pitch or asphaltum and prevent it from flowing, thereby making it possible to maintain a thicker layer in place on the slope of the roof than would otherwise be the case. A gravel or a slag layer also serves another very useful purpose, namely, that of a fire retardant of no mean efficiency, the particles of stone or slag serving as an insulating layer and protecting the pitch and fabric from the action of sparks or embers.

The slag or gravel should be of such a grade that no particles will exceed three-quarters of an inch or be less than one-fourth of an inch in size. It should be dry and free from dust and dirt. In cold weather it should be heated just before using. Not less than four hundred pounds of gravel or three hundred pounds of slag should be used per 100 sq. ft.

PATCHING DEFECTIVE WORK

Where leaks are discovered in the completed waterproofing, the membrane around the leak must be cut out, the trouble traced to its source, and the hole plugged. The difficulty encountered in stopping a leak will emphasize the advantage of making a water-tight job in the first place.

Application of Waterproofing.—Any masonry that is found to leak at any time prior to the completion of the work must be cut out and the leak stopped by applying layers of fabric and cementing compound as described on page 457. Each piece of fabric should be a little larger than the previous one. A layer is of no value unless it is larger than the one under it. Do not attempt to patch the seal while it is dirty, cold or damp; it cannot be done properly.

CHAPTER IX

INSPECTION OF CONCRETE SIDEWALK, CURB AND PAVEMENT CONSTRUCTION

There are certain rules that must be observed in concrete sidewalk, curb and pavement construction, and success depends entirely upon how much attention is given to same. Many sidewalks, curbs and pavements are built which, sooner or later, become more or less defective. While defects may be found in concrete sidewalks, curbs and pavements, it is probable that these defects may be traced to the contractor or inspector, owing to the lack of knowledge of the materials used in construction; to inexperience; or to neglect in appreciating the importance of minor details. The cause of these defects will be pointed out and a means by which they may be avoided suggested.

Art. 51. Concrete Sidewalks

Concrete sidewalk construction is a task for experienced and skillful workmen which is often undertaken by unskillful and inexperienced workmen without adequate supervision or inspection. Its inspection demands close attention to many small structural details which have been proved essential to good workmanship and to the skill and honesty of the men doing the work. Defective work frequently results from failure on the part of the builder or the inspector, to appreciate the importance of watching closely these smaller details, which are considered by some as of minor importance. In other words, durability in sidewalk construction, like almost every other good quality in concrete, depends entirely upon consideration of apparently small details. The necessary qualifications for the construction of sound and lasting work are good materials, proper methods and careful workmanship. Failure to provide these will often result in disappointment. Poor workmanship and neglect of correct principles of construction are responsible for practically all failures that occur in this class of work. Failures which can be positively charged to poor materials are few, though frequently materials are used which could be improved by a more careful and intelligent selection, without adding to the cost of the work.

It is not uncommon to hear, as an argument to prove proper workmanship in a defective walk, that the same workmen had laid satisfactory walks by the same methods. Simply because one job was laid without any regard to proper method of construction and is satisfactory, is no argument that the same can be repeated, as the con-

ditions vary in every case. The weather conditions at the time a walk is constructed has a marked effect upon its behavior, and is not always the same, so that a walk placed on a damp, cloudy day has a better chance than when it is hot and dry, and no precautions are taken to prevent the work drying out too fast. The drainage and foundation of the work may be entirely different, and the gravel used may be more evenly proportioned, as in no quarry or pit does it run the same entirely throughout.

Designation of Concrete Sidewalks.—Sidewalks composed of Portland cement, sand and broken stone or gravel in the base, and Portland cement and sand or granite screenings (or other screenings) in the wearing surface are variously called: "Artificial Flags," "Artificial Stone Flagging," "Artificial Stone Sidewalks," "Artificial Walks," "Cement Concrete Sidewalks," "Cement Sidewalks," "Cement Walks," "Concrete Sidewalks," "Concrete Walks," "Ferrolithic Walks," "Granolithic Cement Concrete Sidewalks," "Granolithic Sidewalks," "Granolithic Walks," "Kosmocrete Walks," "Metalithic Walks," "Monolithic Walks," "Portland Cement Concrete Sidewalks," "Portland Cement Flag Stonewalks," and "Portland Cement Sidewalks."

The styles of construction, however, vary less than the names by which Portland cement concrete sidewalks are designated.

GENERAL REQUIREMENTS

Methods of constructing concrete sidewalks must be employed which will avoid settlement cracks, upheaval by frost, crumbling due to work done in freezing weather, contraction and expansion cracks, separation of top from base, and disintegration.

Thickness of Walk.—The thickness of the walk should be determined by the location, the amount of travel, and danger of being broken by heavy bodies falling on it, or by frost.

Business front walks should not be less than 4 in. and may be 6 in. thick with profit. The top coat or wearing surface of business walks should not be less than 1¼ in. thick, and for driveways subjected to excessive wear, the wearing surface should be at least 1½ in. thick, preferably 2 in. thick.

In residence districts the wearing surface should not be less than 1 in. thick, and the thickness over all for different widths of walks should be as follows:

4	feet wide should be 3½	in. thick.
4½	feet wide should be 3½	in. thick.
5	feet wide should be 4	in. thick.
6	feet wide should be 4½	in. thick.
7	feet wide should be 5	in. thick.

All other widths less than the above should be 3½ in. thick at the center and at the edges 3 in. thick.

Size of Blocks.—The size and shape of blocks or flagstones into which a walk is divided are governed largely by the width of the walk, the local practice and personal tastes. Blocks nearly but not

quite square have a better appearance than those which are distinctly oblong. The slabs should not contain over 36 sq. ft. of surface, and should not be over 6 ft. in any one direction without being reinforced.

Transverse Slope of Walk.—To prevent water from lying on the sidewalk, it must not be level, but slant or "grade" a little to one side, so that rain water will drain off. If the sidewalk has not a considerable longitudinal slope, it should be given a transverse slope of about a quarter (¼) of an inch to the foot to provide for draining the surface. Some cities build their walks with a slope of about ⅜ inch to the foot toward the gutter. The transverse slope should never be more than ⅜ of an inch per foot. A slope of ½ in. per foot gives an unpleasing appearance, and, when the walk is icy, pedestrians slide toward the gutter, particularly on a windy day.

Curving Upper Surface of Walks for Drainage.—When the walk is laid on comparatively level ground in a public park or on private grounds, it should be crowned to drain the surface. The straight edge, employed to level the surface of the walk, may be cut in an oval form, pressing the surface concrete into a convex form, and thus providing a surface from which all water will easily drain. The height of the center should not be too great or it will make it unpleasant to walk upon same, if the walk is narrow, yet must be high enough to readily allow the water to drain off. If the center is raised ¼ of an inch per foot of half width, the surface will always be practically dry, provided it is an inch or more above the adjoining surface, and provided dead grass and leaves are not allowed to wash against the standing grass and form a dam.

Sidewalks are very seldom drained by curving or crowning the upper surface, it being much better to slope the walk as mentioned above. There are two principal objections to laying sidewalks with a crown, one being that one-half the drainage is on the wrong side, i. e., away from the curb or gutter; and the other that they are particularly ugly at points of intersection on account of the hollow left. A crown on a cross-walk, however, if not too high, is very desirable and preferably it should be very slight in the center of the walk and rather steep at each side, where the road material banks up against it.

Street Signs.—Names of streets may be indicated by inserting colored letters in concrete sidewalks at the corner of the block. This may be done by placing wooden or metal letters of a thickness equal to the wearing surface around them, and then removing the letters and filling the space with colored cement mortar.

CONCRETE MATERIALS

The selection of materials is the first consideration and is an important matter. Great care must be exercised in the selection of the various materials used in the construction of concrete sidewalks, for if any defective material is used it will be bound, like poor workmanship, to show in a short time.

Cement.—Only the most uniform, sound, strong, slow-setting Portland cement should be used, one that has been manufactured and known for a number of years and that has become recognized as a standard for sidewalks. Rosendale and other forms of natural cement, as well as Puzzolan cement, are not suitable for this work, the former because of its low strength and inability to resist abrasion, and the latter because in work above ground it is weakened by the action of the atmosphere. Nothing can take the place of standard Portland cement, and care must be taken to secure a good grade. A cement of improper quality will cause cracking. The cement should comply with the Standard Specifications for Portland Cement of the American Society for Testing Materials, adopted June, 1904, together with subsequent changes and amendments. The characteristics of good Portland cement are treated in Art. 4, page 43.

Many attempts have been made to use natural cement for the concrete base of the walk and Portland cement for only the finishing coat or wearing surface. This practice, however, is not to be commended, owing to a tendency for the two to separate. This probably is due to the fact that the Portland cement mortar was put upon the base before the base was set and the difference in the amount of contraction of the two concretes, while setting, prevented a union being formed.

Sand.—The sand must be clean and coarse, graded in size from medium to coarse grains, free from dust, loam, or other foreign matter. At least 75 per cent of a sand should be retained on a 40-mesh sieve, with the particles well distributed between that size and the size passing a 4-mesh sieve, with an increasing proportion on the coarser sieves. Avoid the use of sand that is too fine (see Art. 8).

Limestone Screenings.—The use of limestone screenings in sidewalk concrete is not advisable. While limestone screenings may prove a success in concrete used in foundations and underground work, they have not shown the same efficiency in sidewalk concrete where they were exposed to the elements and to extremes of heat and cold. Limestone expands on receiving moisture and contracts in drying, and this action will cause hair cracks.

Broken Stone.—Broken stone for concrete should be a good hard stone, giving many angles in the fracture, and that will not be affected by the weather. It should be screened dry through a 1¼-in. mesh and be retained on a ¼-in. mesh. It should be free from dust, dirt, or other foreign substance (see Art. 10).

Gravel.—If gravel is used, it must be washed river or beach gravel, free from clay, loam dust or other foreign matter, and varying in sizes from that retained on a ¼-in. mesh to the largest passed by a 1¼-in. mesh (see Art. 9).

If unscreened gravel is used, it should be clean, hard, and contain no particles larger than 1¼ in. The proportion of fine and coarse particles must be determined and corrected to agree with the requirements for broken stone concrete.

Grit Screenings or Crusher Dust.—These are for the wearing

surface and should be of crushed quartz, granite or other hard, tough stone, free from all foreign matter, and crushed so that the largest piece will pass through a sieve of $\frac{1}{4}$-in. mesh, the particles graded in size from fine to coarse, the crusher dust to contain not over 25 per cent of fine dust (see Art. 8). Sand does not make as good a wearing surface as broken stone or gravel screenings.

Water.—It is a common practice for sidewalk men to use water from gutters and drains on their work and then blame the cement for failures. Water should be reasonably clean, free from oil, acid and alkalis. Clear rain or river water is best, since water from wells or springs oftentimes contains acid or other deleterious matter. Water should be fresh and free from earth, dirt or sewage. A soft water, clean and clear, used not too cold, will give the best results (see Art. 12).

Boards.—All material used in the work should be placed on clean boards, and the inspector should reject any not so placed.

Material from Old Concrete Walks.—Where old concrete walks are torn up during the progress of the work, the contractor is sometimes permitted to recrush the concrete and use it in the base of the new walk.

GRADING FOUNDATION

The sidewalk should be excavated and graded to the depth and width shown on the drawing having reference thereto, including all wings and crossings, as shown on plan, and to the levels given on the ground by the engineer. The site should be carefully staked off, running the lines such a distance apart that the distance between them is about 4 in. wider than it is desired to make the finished walk. The grading must be smoothly and neatly done, all large stones, boulders, roots, sods and rubbish of every description being removed from the grade, and the entire work must be made to conform fully to the profile and the grade of the walk when finished. It is well to do the excavating and filling some time before the concrete is put in, thus securing thorough setting.

Depth below Grade of Walk: Slope.—The excavation should be made to the sub-grade previously determined upon. It is not possible here to state exactly what the depth of excavation should be, as it depends upon the climate and the nature of the ground, being deeper in localities where heavy frosts occur or where the ground is soft than in climates where there are no frosts. In the former case the excavation may have to be carried to a depth of 12 in. or more, whereas in the latter from 4 to 6 in. may be sufficient. The sub-grade should have a slope toward the curb of not less than $\frac{1}{2}$ in. per foot.

Excavations.—In places where cutting is necessary to bring the sidewalk to the required grade, no plow should be used below a line 3 in. above the surface to which the sub-grade is to be graded. The remaining three inches should be carefully dressed off with picks or other hand tools. The excavation should be kept free from water.

Consolidation of Trenches, Etc.—All trenches or excavations that have been made for, or in connection with sewers, private drains, gas or water pipes, telephone or electric wires, pipes or conduits, etc., and which are not thoroughly settled, should be opened out and refilled, in 6-in. layers of gravel or good earth, well tamped, and watered if necessary, until solid.

Defective Places.—All soft, boggy, spongy or defective places encountered in excavation or elsewhere, should be wholly removed to such depth and extent as may be necessary, and all depressions filled with suitable filling material (preferably gravel), which should be thoroughly compacted by flooding and tamping in layers not exceeding six inches in thickness.

Boulders, Trees, Etc.—All boulders, stones, stumps, walls or other obstructions found upon the line of work should be removed. All roots of trees and other wood or material liable to decomposition should be carefully removed. So should pieces of sod or turf, and other obstructions to a clear excavation. Trees should not be injured, cut down or otherwise disturbed except by order of the engineer. Roots of trees which are not removed, but which are contiguous to the line and grade of the walk or in any way interfere therewith, should be properly trimmed and cut away. Any tree removed should be grubbed for the entire width of the sidewalk and also its roots that rise above the level of the sub-grade. Large roots are sometimes covered with earthenware half-pipes.

Upheaval by tree roots can very easily be avoided by cutting out any roots which will run under the pavement less than a depth of six inches under bottom of drainage foundation. The heaving and throwing of walks, however, so often attributed to tree roots growing up under the walks, is more often the result of the movement of the earth caused by the swaying of nearby trees, especially large ones. Roots, however, do grow close to the concrete walk, as they find moisture there, and elm and maple roots should be looked after especially, as they are likely to cause the most trouble.

Surplus Material Required by City.—Old lumber, stone flagging, dirt, or other materials of value arising from the work or any portion thereof, should not be thrown away, wasted or otherwise disposed of without the engineer's written sanction. The inspector should see that the above mentioned surplus materials are conveyed and disposed in such places as may be directed by the engineer, and that none of the excavated material is piled upon the sides of the walk, except by the engineer's permission.

Surplus Material Not Required by City.—Where surplus materials are not required by the city, the inspector should see that they are disposed of by the contractor in such a manner as not to cause a nuisance, injury or inconvenience to the city or to public or private parties.

Cutting below Sub-Grade.—Excavations below the proper level of sub-grade should be made up with suitable material, solidified by ramming.

Slope of Cuts.—In cutting, the contractor should be required to

excavate for a sufficient distance to give a slope of $1\frac{1}{2}$ horizontal to 1 vertical from a point one foot from the sidewalk.

Deep Fills.—When the sub-grade occurs on fills its preparation requires very careful attention. Many foundation failures can be traced to improperly made fills. The material to be supplied in case of a fill should be good earth and the upper portion of the fill should be tamped in layers not to exceed 6 in. in thickness, and each layer thoroughly packed by rolling or tamping. In no case should a fill be compacted in layers exceeding 10 in. in thickness. The fill should be flooded with water in order to thoroughly settle it. Care must be taken to see that fills are thoroughly compacted and are free from large stones or perishable materials.

The top of all fills should extend at least 12 in. beyond the walk on each side. If fills are narrow they wash or cave down so that the edge of the sidewalk slab is left overhanging to tip or break down under load. Many failures can be attributed to fills having been made too narrow and then left unprotected.

The sides of the fill should be given a slope of about $1{:}1\frac{1}{2}$, so that it will not slip away, and when granular materials are used, the slope should be banked with sod or clay.

No concrete sidewalk should be constructed upon any embankment until the same has sufficiently settled to afford a stable foundation. The embankment must be made proof against being washed out.

Damage to Areas, Window Openings, Stop-Cock Boxes, Etc.—In excavating for foundation for sidewalks, care must be taken not to damage the window openings, areas, coal chutes, traps, lamp posts, hydrants, or water works stop-cock boxes, down pipes or other openings or appliances that may be in, or under, the present walk, and care must also be taken to prevent material of any description falling into the stop-cock boxes, or in any way injuring or affecting them so as to interfere with their proper working. Wherever it is found necessary to cut or alter private walks or driveways, they should be repaired or replaced in a satisfactory manner.

Manner of Removing Existing Walks.—The contractor should be required to remove existing walks in small sections only, sufficient to carry on the day's work, and so as to interfere with the business of the street as little as possible. At the close of each day's work the walk should be left in such a state as to insure perfect safety to the public. Lamps should be provided wherever necessary, and in instances it may be advisable to enclose portions of the walks by barricades.

PREPARATION OF SUB-BASE

Upon the sub-grade prepared as above and after inspection and acceptance of the same, should be placed the sub-base.

Thickness of Sub-Base.—The thickness of the sub-base may vary from nothing to twelve inches. In localities unaffected by frost and having soil sufficiently porous to carry off the surface water, the sub-base may be omitted entirely, and the concrete laid upon natural

ground excavated to the required depth; but in clay soil in northern climates twelve inches of sub-base may be required. An average thickness of a sub-base is 4 to 6 in., although in warm climates, if the ground is firm and well drained, the sub-base may only be 2 or 3 in. thick or omitted altogether as stated above.

Materials for Sub-Base.—The materials for a sub-base, where such is required, should be clean, hard cinders, slag, broken stone, coarse sand, gravel, broken bricks, or other similar materials. In order to make it more porous, broken stone or gravel should be screened. Whatever material is used it should be of such a character that it will withstand tamping without crushing to an extent that will prevent proper drainage. The best material for this sub-base is broken stone varying in size from ½ in. to 3 in. Steam cinders, however, are more commonly used, on account of being cheaper than broken stone. Care must be taken to eliminate the fine material from the cinders. Shells are sometimes used. Ashes are also used to some extent.

Placing and Compacting Sub-Base.—Whatever material is employed it should be evenly spread upon the sub-grade, should extend at least two inches beyond the edges of the walk and should be thoroughly rammed so as to present a firm and unyielding surface. This is a part of sidewalk work which is often neglected. Stone should be sledged and lighter materials tamped with iron tamper.

To allow an excavation or trench to be filled with cinders, etc., without evening or compaction, and then to let it be used for a walk before laying the concrete, is very objectionable, and has proven ruinous to many walks otherwise well made. Cinders that have been placed in a walk for some time before placing the concrete should be picked loose and retamped so that the entire mass has even compaction. If some places are packed harder than others, the flag or slab will not have an even bearing and may break.

A heavy iron roller should be used and the cinders, etc., kept evenly tamped when put in. It is not so much that they are tamped hard as that they are even (edges and middle alike). Care must be taken to see that the top of the sub-base is made smooth and to grade. The author would suggest that where broken brick and cinders are used that in addition to tamping them thoroughly that they be covered with a layer of sand in order to prevent opposite action in expansion from freezing.

The finished sub-base should be kept at least fifty feet in advance of the placing of any concrete.

Wet Material.—While compacting the sub-base the material should be thoroughly wet and should be in that condition when the concrete is deposited. Cinders or sand must be thoroughly wet when being rammed. Enough water should remain in the sub-base to render the surface as moist as the concrete base at the time the latter is laid, or if the work has been delayed, the sub-base should be sprinkled with water as required. If the sub-base is too dry it will absorb from the base the water necessary for the perfect hardening of the concrete. It cannot be too strongly emphasized that one

of the causes of inferior concrete in the base is the absorption of water from the mixture by the porous foundation before it has set; therefore, a thorough wetting of the foundation just before placing the concrete is absolutely essential. The amount of water needed varies with the character of the soil.

Drainage.—The sub-base must have good drainage, otherwise it may be a menace to the walk. If it is more porous than the retaining soil, it will naturally drain this soil and will offer sufficient drainage, but in some soils and under some conditions, additional drainage is necessary. When no additional drainage is provided, water enters the sub-base of the walk through the lawns on either side, and at all the joints between the slabs. Naturally, this moisture is greatest at the sides and near the joints, where it enters, very little reaching the center of the slab. Subsequent freezing causes greater upheaval of the sub-base near the edges of the slab than at the suspended center, and the slab, finally bearing only on the edges, acts as a beam. The load, while not great, is applied continuously and simultaneously, with changes in temperature, and finally causes a flow of the material resulting in depression and permanent set. In other words, if the water is not able to escape into the sewer or elsewhere, it will accumulate in the sub-base, and may be frozen and heave the walk. Therefore, in soil where the sub-base and the natural drainage cannot take care of the water, other drainage must be provided.

The best means of supplying this additional drainage will depend somewhat upon the available outlets, etc. An excellent plan sometimes adopted is to lay at intervals of twenty or twenty-five feet a blind stone drain, about 10x12 in., from the walk foundation to the foundation of the curb. Tile drain may also be provided at suitable points to carry off any water which may collect in the sub-base or under the concrete base. A line of 3-in. diameter, round, butt-jointed, hard-burned drain tile may be used for this purpose, the outlet or discharge for the drain being connected with the street inlets, or in the absence of street inlets by such other arrangements as may be prescribed by the engineer.

It is most important that the sub-base be well drained to prevent the accumulation of water under the walk, otherwise the walk will be heaved up by frost in the winter as described above; and if it does not crack will at least be thrown out of position when the soil again settles. Upheaval by frost is obviated by providing proper under-drainage.

All openings in curbings for outlets into the gutter for cross-drains should be made by a competent stone-cutter, and any curbstone defaced or broken in this operation should be replaced.

Protection of Sub-Base.—No walking on or driving across the prepared sub-base should be permitted. In case this is unavoidable, cross-boards should be placed on the sub-base and plank laid lengthwise on these to prevent packing of one portion more than another, where the walk is much used.

FORMS

After the foundation or the top of the sub-base has been brought to the proper distance below the grade stakes, forms are placed for the walk, being of such shape and dimensions as may be required.

Material for Forms.—When wooden forms are used they should be free from warp and of sufficient strength to resist springing out of shape. They should consist of 2-in. scantling set on edge, and in width being the height of the thickness of the walk (concrete and mortar top). As the minimum thickness of a concrete sidewalk in successful practice is 4 in., 2x4-in. scantlings may be used. Where the walk is to be 5 in. thick, a 1-in. piece, nailed to the top of the 2x4-in. scantlings solves the problem. Surfaced lumber has advantages, but its use is not necessary (see Art. 16).

Where curves are desired in the walk, narrow boards are used instead of the scantlings. The forms for short curves should be made by sawing the proper curve out of an inch plank, and then nailing enough of them together to give the proper thickness. Large curves can be made by using a ½x4-in. plank on edge for the side, and springing it into the proper curve and staking it fast, but care must be taken with the ends of adjacent pieces to secure a uniform curve. Thin strips of metal will generally be found more convenient than narrow boards in forming curved lines.

Cross scantlings are put in at regular distances and at right angles with the side forms. These are used in dividing the walk into equal sized blocks. Ready made metal cross-forms or parting strips of special patented type are now on the market. Metal cross-forms should be about ¼ in. thick, with stiffeners on the ends and top, if necessary. They should be of a depth to correspond to the thickness of the proposed walk, and should extend full width of the walk and be set at right angles to the side forms. They should be left in place until the wearing surface is floated.

Where forms are used for the second time they should be cleaned from all particles of dirt and mortar that may be clinging to them (see Art. 18).

Alignment and Level of Forms.—Forms should be placed in the manner necessary to outline both external edges of the walk accurately, the top of the forms being located to coincide with the established grade of the walk. Care must be taken to maintain a good alignment. The top edges of the forms must be true to grade, as they serve as templates for finishing the walk.

Staking of Forms.—The forms must be well staked to the established lines and grades, the stakes being sufficiently close so that no bulging can occur when the concrete is tamped into place. Stakes are generally driven along the outside of forms every five or six feet. Forms are sometimes held in place by means of stakes driven on each side, those on the outside being much stronger. As the work of laying the concrete advances, the small stakes on the inside of the forms are removed. Generally, the nailing of stakes to forms is not necessary. If forms are held in place by nailing through the supporting stakes into the scantling, these nails should not be driven

"home" in order that they may be easily pulled to release the forms when the work is completed.

Where thin ceiling stuff or sheet iron is sprung for curves, special care must be taken to hold them in place, so they will not crowd between stakes in tamping. Care should also be taken in joining the straight form to these curves, to prevent an unsightly change of direction.

Wooden cross-forms may be held in place by stakes on the opposite side from that on which the concrete is being deposited, a shovelful or two of concrete being sufficient to hold the cross-frame firmly until the concrete is tamped into position. If the special metal cross-frames mentioned above are used, fewer stakes will be needed for the forms, for when the cross-form is keyed into position, it holds the forms in their proper relative position.

Providing for Surface Drainage of Walk.—Forms on one side should be a little lower than the other to provide proper drainage for the surface of the walk. The grade should, of course, be in the direction towards the curb or in the direction of the gutter. A rise of a quarter inch per foot will be sufficient in most cases to properly drain the walk from rain water (see page 465).

Spacing of Forms.—All forms must be so spaced that the inside measurements are exactly those of the "blocks" being molded. The side forms should be marked to show where joints are to come, care being taken that the marks defining a joint are exactly opposite each other on the two scantlings. If wooden cross-forms are used they should be placed so that the face against which the concrete is placed is in line with the marks indicating positions of joints.

Strips at Curbing.—Suitable strips, where there is no curbing, should be set to hold the concrete, and these strips should not be removed until permission is given. As soon as they are removed, earth should be tamped against the edges of the walk.

Wetting Forms.—All forms should be thoroughly wetted before any material is deposited against them. This is of value in preventing the wood absorbing too much moisture from the concrete that is placed next to the form (see Art. 18, page 240).

Removal of Forms.—The forms should not be removed until the cement has set so hard that there is no danger of injuring the edge of the walk in removing them.

CONCRETE BASE OF WALK

The base of the walk consists of a layer of concrete deposited on the foundation or sub-base and carrying a surface layer or wearing coat of cement mortar. Its functions are to furnish a solid foundation for the wearing surface and to give transverse strength to the walk, transmitting the pressure uniformly to the foundation or sub-base. The concrete in the base of concrete walks is generally the most inferior concrete made. The capital and equipment necessary for laying concrete sidewalks is comparatively small, and the con-

struction work apparently easy, the result being that many walks are put down by inexperienced contractors and competition has reduced the price so that good work cannot be done profitably, consequently the inspection must be exceptionally close at this stage of the work.

Proportions.—Materials for concrete should be proportioned according to the voids in the aggregate, which varies with different materials (see Art. 13). The concrete may be mixed in proportions of 1 part Portland cement, 2 or 3 parts coarse, clean sand, and 4 or 6 parts broken stone or gravel, depending entirely upon the strength of the work required and the nature of the sand and broken stone or gravel. If the ground is firm and the sub-base well rammed in place and properly drained, great strength will not be required of the concrete, which may, in such cases, be mixed in about the proportions 1:3:6.

Thickness of Concrete Base.—The concrete base should not be less than three inches thick. Four inches is much better and is recommended for general use in sidewalks, while in some cases five or six inches are required (see page 464).

Mixing.—All proportions should be by actual measurement in boxes or other suitable receptacles, and no material should be used which has not been thus measured (see Art. 14). The concrete may be mixed either by machine or hand, as described on pages 167 and 176. Mixing is frequently neglected in sidewalk work and it must be carefully watched. Thorough mixing must be rigidly adhered to, as well-mixed concrete is more dense than poorly mixed, and requires less tamping.

Especial care should be taken to avoid the use of too much water in the manipulation. The concrete should be mixed to such a consistency that when rammed the mass will not quake like jelly, but will, when struck, compact within the area of the face of the rammer without displacing the material laterally. That is to say, the mass of concrete, when ready for use, should appear quite incoherent and not wet and plastic, containing water, however, in such quantities that a thorough ramming with repeated though not hard blows will produce a thin film of moisture upon the surface under the rammer, without causing in the mass a gelatinous or quick-sand motion. In other words, the concrete should be just short of quaking. An excess of water must be avoided. It is not practicable to use as wet concrete in sidewalk construction as in some other classes of work. If the concrete is too moist, the mass will shake like wet clay; if it be too dry, it will rise up around the rammer like sand. In either case, the mass cannot be suitably compacted by ramming, and will therefore be comparatively weak and porous after setting. The top coating should have much more water than the lower layer and be of such a consistency as to work well under a trowel.

The concrete should not be mixed in larger quantities than is required for immediate use.

Size of Batch to Be Mixed at One Time.—The size of a batch of concrete should be governed by the speed with which it can be

mixed and deposited. A batch should not be made that is larger than can be placed within thirty minutes' time or less, generally not over a cubic yard. Some specifications state that only one barrel of cement shall be used to a batch. The quicker the concrete is placed, tamped and surfaced, the greater the chances of success; for on hot, quick-drying days the mortar often begins its initial set even before the half-hour period.

Retempering.—One of the common mistakes made by inexperienced workers is to mix too large a batch at one time; and then when the mortar has begun to set before it could be placed, to attempt to remix or retemper same. Under no circumstances should this be done, as once concrete or mortar has taken its initial set, or begun the hardening or drying out process, the addition of water or mixing will not delay this process. Any remixing of concrete after hardening has begun will generally weaken it to such an extent as to make it unsatisfactory. The saving which may result from the use of a portion of a batch of concrete which is retempered will not justify the introduction of uncertainties into the work. Retempered concrete should not be used. Any concrete left over at quitting time should be wasted.

Transporting Concrete.—In transporting concrete, care must be taken to prevent loss of material in any way. Wheelbarrows must not be overloaded. Loss of any surplus water in the mixing may rob it of a portion of the cement carried in suspension (see Art. 23).

Placing Base Concrete.—The concrete should be deposited within the forms on a sub-base previously wet and tamped into final position as soon as possible. The surface of the concrete should be brought to a plane parallel to the proposed finished surface of the walk, and at a distance below it equal to the thickness of the wearing surface. To insure this the concrete should be struck with a straight edge, long enough to span the walk and notched out at the ends so that when placed on the side forms the straight edge will define the correct grade of the base.

The concrete should be dumped, not thrown or dropped from a height, as this tends to separate the stone from the mortar. No concrete should be placed upon a dry sub-base. If this precaution is not taken it is certain that the porous material, absorbing a considerable quantity of water, will rob the concrete of much of the moisture it needs for proper crystallization and curing.

Tamping Base.—The concrete in the base of concrete walks is generally the most inferior concrete made. Even with as good material and workmanship, it is hardly possible to get as good concrete in cement sidewalk base as in structures of larger volume, such as retaining walls, abutments, piers, etc., as in tamping a thin layer of concrete laid on a cinder bed or a sub-base of other materials, the concrete may compact a little under each blow, but a great part of the force is expended in forcing the concrete up at another place and possibly dislodging the sub-base. This is one of the reasons why it is necessary to have the sub-base thoroughly compacted before placing concrete, and why it is advisable to so mix the concrete and

have it of such consistency as to reduce as much as possible the amount of tamping necessary.

The concrete should be thoroughly tamped or rammed until water appears on the surface. If the concrete quakes it is an indication that too much water was used in the mixing. The concrete should be compressed sufficiently by the tamping to give the right depth for the wearing surface. It is important that the upper surface of the concrete base should be exactly parallel to the top of the finished walk. To determine whether this condition has been fulfilled, the straight edge or gauge mentioned above should be drawn over the tops of the side forms, and should clear the concrete at all points. The tamping should be as thoroughly done at edges and corners as in the center of the slab. Particular care must be taken that the concrete base is well rammed and consolidated along the outer edges, so that frost will not break them up. This point is often neglected, because tamping the edges is likely to crowd the forms out of place. In ramming, especial care must be taken not to disturb the forms.

Concrete that has begun to set before ramming is completed should be removed from the work. No patching of defective work after the concrete has begun to set should be allowed.

Concrete may be tamped with iron-shod rammers, seven inches square, and weighing about twenty pounds. For tamping next the forms, the makers of cement working tools offer a lighter rammer with square face at one end and blunt, chisel-shaped tamper at the other. (See page 301.)

Preserving Joints in Base.—The concrete is now cut into blocks exactly corresponding to the proposed blocks in the wearing surface. There are several methods employed for dividing walks into blocks. One is to place a wooden cross-form along the walk at regular distances and at right angles with the side forms to correspond with marks previously made on the forms. After the concrete in any section has been thoroughly tamped, the cross-form should be removed, together with the stakes that support it. Against the joint thus made bare, clay or loam mortar may be plastered (¼ in. thick); or paper or felt ¼ in. thick may be placed; or against the joint may be placed a steel divider 6 in. high and ¼ in. thick. The perpendicular wall of the new concrete slab must be carefully preserved, the next slab be tamped against the clay, loam, mortar, paper, felt or the steel divider, as the case may be. If the steel divider is used it should be removed by slightly tapping, leaving the joint dividing the slabs open; if paper is used the part projecting above the concrete should be trimmed off with shears; if clay is used no further treatment is necessary. If desired the slabs may be tamped directly against each other. The author, however, prefers to leave a clear space between each slab. For this purpose a piece of thick soft paper, or tar paper, may be used for separation as mentioned above. Some prefer a piece of sheet steel, to be removed after the blocks are made.

Ready made metal cross-forms or parting strips of special pat-

ented type may be used instead of the steel divider mentioned above. In this case, the metal cross-form is left in position until the adjoining slab is placed complete with wearing surface, being raised just as the slabs are receiving their final treatment and the groover run over the space from which it has been removed. If preferred, the metal cross-form may be removed after the concrete for the next block is in place and before the wearing surface is placed.

Another practice which was common a number of years ago is to lay alternating slabs entirely independent of each other. After the first set is completed, the alternate positions are filled. This scheme made positive joints and prevented breaking of slabs on account of settlement. Some recent specifications in the author's possession still specify that the "Blocks" shall be laid alternately in frames 2x4 in. or 2x5 in., dressed scantlings held in place by stakes and braces, strips of tar paper being placed in the joints. One of them requires that no adjoining blocks shall be laid within six hours of each other, and the requirement is also made that where spalling, splitting off or other defects occur after completing the entire block or division must be replaced with a new block or division, no patching being allowed. The objections to laying the alternate blocks in a walk are that it is hard to get the different blocks in a true plane, the appearance, therefore, is not so good. Another objection is the increased cost and time required.

Sometimes a long stretch of concrete for the base is placed and a straight edge is laid across the walk in line with the marks previously made on the side forms to define the joints, and with a spade or special tool the concrete base is cut entirely through to the sub-base. The joint in the base is then filled with clean sand. This practice is not to be recommended, and especially when dependence is placed upon cutting through both the top and base at the same time. Results of this type of construction are to be seen in a number of places. However, if such a practice is employed, the tool for cutting the walk up into blocks should be so shaped as to make the top edges of the groove firm, smooth and slightly round, and should be long enough to cut entirely through the top coat and the concrete base.

Do not allow the joints to become filled with cement after being made, thus defeating the purpose for which they were made.

Avoid Fractional Slabs.—In closing work at night or at the noon hour, the concrete should be finished at a joint with a square straight end. A part of a slab or block should never be molded and then built after having stood long enough to begin to set. Any concrete left over after finishing a slab should either be mixed in with the next batch, if this is to follow in a very short time, or it should be discarded. The inspector should see that fractional slabs are avoided, otherwise a crack will probably occur in the wearing surface above the line of division between adjacent batches. The concrete must be tamped against the cross-forms so that when placing of concrete is resumed, it will start from a vertical joint between abutting slabs as mentioned above. If the concrete is finished with a ragged oblique

edge, it is impossible to get a good union between work cast at different times and expansion by heat is liable to cause one piece to slide upon the other and break the wearing surface. Under no circumstances should a section of the base be left partially completed to be finished with the next batch or left until the next day. The work may be stopped at night most conveniently by inserting a board between the side forms and finishing the walk against it.

Expansion Joints.—Many failures in concrete sidewalks result from expansion, and to take care of this there should be, in addition to the block joints, extra joints provided. Expansion joints should be constructed as specified. The usual practice is to provide expansion joints at approximately every 50 feet and at all street and alley returns, their thickness depending upon climatic conditions. The expansion joints should extend through the entire thickness of the sidewalk proper.

The concrete base should not be allowed to bear directly against any solid body, such as curb, area step, or coping, wall of building, lamp post, telegraph or telephone pole, man-hole rim, etc., but leave at least the same space as between the blocks themselves (generally ¼ in.), so as to avoid cracking and chipping due to expansion and contraction from temperature changes. This space can be conveniently provided for by the use of thick tar paper or felt. It is sometimes specified that a clear space of not less than ½ in. must be left between the back of the curbing (or other such fixtures) and the abutting ends of the sidewalks for the full depth of the walk. There is likely to be some settlement, either in curb, curb wall or adjacent sidewalk, and irregular cracks will result.

Expansion joints are usually filled with sand. It is not necessary or desirable to have sharp sand; sand with rounded grains will answer better. Paving pitch and asphalt have also been used for the large joints and will prevent to some extent moisture reaching the sub-base. If a tar expansion joint is used, the upper half inch of the joint should be filled with sand to prevent the tar from being tracked over the surface of the walk. (See page 503.)

Care of Base.—Workmen must not be permitted to walk on the base before the top surface is laid, as it is positive to place more or less foreign matter upon same, and thus make a weak spot in the work. Care must be exercised to prevent sand or any other material from being dropped on the concrete, and thus preventing a proper union with the wearing surface. Where sand or dust gets on the base it must be carefully removed before the wearing surface is applied. (See Art. 29, page 335.)

WEARING SURFACE

As soon as a few of the blocks of concrete have been laid, the top dressing or wearing surface should be applied immediately, and before any of the blocks have set. The lack of adhesion between the base and wearing surface is one of the most frequent causes of failure in concrete sidewalks. The preparation and application of

the wearing surface requires much care if satisfactory results are to be obtained.

Materials.—The wearing surface should be laid with the same first-class Portland cement as in the base. No more than one brand of cement should be permitted to be used in the wearing surface in front of any property or on a street block, as the case may be.

Either sand, or fine crushed rock, or a mixture of the two, may be used to form the mortar. Usually a coarse sand or fine gravel is used for the aggregate. If crushed rock is used it should be of a texture such as granite or trap, which will break into cubical, rather than flat or laminated fragments. Some granite screenings, however, contain mica, hornblende, and feldspar which render them undesirable for use in concrete walks. Crushed quartz is best for this purpose. Pure silica sand is entirely satisfactory. The aggregate should be screened through a quarter-inch mesh, and there should not be a large proportion of very fine material.

Sand, if used, must be clean and free from any trace of loam, as this is certain to make "soft spots" which soon show wear. It is of the highest importance to see that the sand is of the proper quality, as sand frequently contains a considerable proportion of soft and easily decomposed constituents which renders it entirely unfit for use in the wearing surface of concrete sidewalks, since the friable grains soon pulverize and blow away, which not only looks badly but also tends to hasten the destruction of the walk.

Proportions.—The proper proportion of sand to cement depends upon the voids in the sand (see Art. 13). There should be enough and only enough cement to fill the voids. If there is not enough cement to fill the voids, the sand will not be held with the maximum strength; and if there is an excess of cement, which is very often the case, the walk is liable to crumble under travel, since neat cement will not resist abrasion as well as sand and cement.

Customary proportions are 1 part of Portland cement to 1 or 2 parts of fine aggregate. If mortar richer than 1:1 is used, it is likely to check or crack in setting, marring the appearance of the walk, and may cause the walk to crumble under travel. The author does not recommend mortar richer than a 1:1½ mixture. It is better to avoid too great a variation between the richness of the wearing surface and that used in the base. A 1:3 mixture of cement and sand is sometimes employed, but this is not a mix sufficiently rich for walks subject to the average wear.

A good wearing surface may be obtained by using one (1) part of Portland cement, one and one-half (1½) parts of coarse sand and two and one-half (2½) parts of pebbles or crushed granite or other approved stone as may be selected, screened to pass ½ in. and be retained on ¼-in. screen. Where both fine and coarse aggregates are used in the mixture for the wearing surface, a 1:1½:3, or 1:2:3, or even a 1:2:4 concrete with Portland cement, sand or stone screenings and crushed or screened gravel may be used, screened in the proportions stated above.

Thickness of Wearing Surface.—The thickness of the wearing

surface varies in practice from ½ to 1 in. Usual thickness is about 1 in. The thickness of the wearing surface, however, is governed by the service to which the walk is put. Business districts require greater thicknesses than residential districts (see page 464).

Mixing.—The materials should be very exactly proportioned, so as to give a uniform color. All proportions should be obtained by actual measurement in boxes or other suitable receptacles, and no material should be used which has not been thus measured (see Art. 14, page 152).

The mixing should be done in suitable boxes or upon tight platforms (see Art. 15, page 176). The materials should be thoroughly mixed by turning at least three (3) times dry. Water should then be added in a fine spray and the mass turned twice (2) wet, *not including shoveling into wheelbarrows,* or pails, as the case may be. Care must be taken that there is not too much water in the mixture, but sufficiently pasty to work with a trowel. An excess of water in the mixing is likely to crack the finishing mortar, due to great shrinkage.

Consistency of Top Mortar.—The proper consistency required will depend upon whether the top mortar is to be floated or is to be tamped. If the top mortar is to be placed by floating under straight edge it should be mixed wet enough to "float" readily. A mushy consistency about like mortar used by a mason in laying brick is about right. If the mortar is mixed too stiff it cannot be readily leveled with a straight edge, and if too thin it takes longer to dry out ready for finishing and is apt to result in sandy spots or to cause pock marks. If the top mortar is to be tamped down with the base, the consistency should be such as to permit of thoroughly tamping and allowing a film of moisture to appear on the surface.

Placing Top Mortar.—The top mortar should be placed immediately after the base is tamped into position. This may be done by floating or by tamping. The most common way of placing the top mortar is to float it, by making the mixture very thin, and then spread it regularly, and work it down with a straight edge until the surface is a true plane flush with the top edges of the forms. The mortar should be spread heavily on the surface of the concrete by means of a trowel, care being taken that no air spaces are coved, and that the trowel is run along sides so that the edges will become dense. The trowel should not be used to smooth the mortar top, but take a straight edge, the back of the concrete straight edge will do, if straight; with this resting on the side forms, stroke the mortar off even. In holding straight edge slightly slanting it will pack the mortar some.

Another method is to apply the mortar to the base, mixed with less water, so as to be stiff, and spread evenly and somewhat deeper than the final wearing surface. The mortar should then be tamped with a light rammer and beaten with a wooden batten to break any air cells and make the mortar finish perfectly solid. The surface should then be struck off with a straight edge bearing on the top of the side forms. Some hollows or rough places will remain, and the

straight edge should be run over a second or perhaps a third time, a small amount of rather moist mortar, made from thoroughly screened sand, having been first applied to such places. Care must be taken to see that all low spots are brought to proper grade. A top mortar put on in this manner can be finished with much less delay than can the floated top mortar.

Choice between Floating and Tamping Top Mortar.—The author is of the opinion that at least 75 per cent of all sidewalk men put in their concrete base, and especially the top mortar or wearing surface entirely too wet. It is not uncommon to hear, as an argument, that by so doing the top mortar bonds better with the concrete base, but as a matter of fact this reason is fallacious. On the other hand a mortar top is very likely to show a different degree of construction in setting from the concrete base, and when it is troweled in finishing, neat cement is flushed on the top and forms a thin, brittle surface that is very apt to scale off in time. Besides this, if the mortar has been mixed too thin (as it generally is when it is to be floated), the finishers have to wait around until the surface is dry enough for finishing or surreptiously sprinkle dry cement on it to take up the superfluous moisture. The surface should be finished before any portion of the particles commence to crystallize. To disturb these particles by troweling a half hour later is apt to cause hair-cracks and crazing.

The author would suggest that the top mortar be put on with only a little water in it and then tamp it thoroughly until moisture appears on the surface, making it possible to finish in the usual way. If the mixture is of the proper consistency and the top properly applied, a more perfect bond between the top and base is assured. The tamping gives a dense, close-grained top. There is also much less danger against checking and crazing. It is frequently argued that tamping the top mortar adds to the cost of the work, but the author is of the opinion that it is cheaper to pay for a little more tamping than to have finishers waiting around for the surface to dry out, especially when they are drawing extra pay after quitting time.

Top Mortar Flushed from Base.—A mortar top or wearing surface may be obtained by using a base concrete rich in cement and tamping it until the mortar rises to the top. This method does not produce as perfect a surface as is secured by using a separate coat of mortar as mentioned above, but for many walks can be employed. Considerable time is saved by this method, as the work is finished as fast as the workmen cover same, without the necessity of going back to put on the wearing surface.

In placing a walk of this construction the base mixture is well heaped above the forms and then tamped to grade. The usual tamping may be followed by a special tamper which will assist in forcing the coarse stone from the surface and in bringing mortar to the top. This tamper is made by bending a piece of scrap-iron and bolting it together to form a square of about 9 in. on the side, and then short cross-bars are bolted to this at about 3/4 in. apart, inside the square. Four pieces of iron rod are then bolted to the four corners

of tamper and brought up to a handle for operating same. This tamper can be made very easily by any blacksmith. The cross-bars assist in forcing the large stone, etc., down into the mass, and in bringing the fine particles to the surface. The surface should then be leveled and smoothed by straight edge and finished in the usual way.

To Avoid Loose Tops or Wearing Surface.—A great many failures are due to a lack of bond between the top coat or wearing surface and the concrete base. The placing of the top mortar must receive the closest attention in order that it may be properly bonded to the concrete base. A hollow sound produced in walking over a concrete sidewalk is an almost infallible sign of a poor bond between the top mortar and the concrete base, which eventually will result in breaking up or cracking of the surface finish over the concrete, greatly disfiguring the walk. It is of the utmost importance that the mortar top be applied before the concrete base has begun to set.

Loose mortar tops are usually caused by the drying out and the setting-up of the concrete before the top surface is placed and then failure to take the proper precautions to prepare the concrete surface for the mortar top. The sooner the top mortar can be applied after concreting the more thoroughly it is pressed down (preferably tamped) into the concrete base and the rougher the surface is, the better will be the bond between the two materials. If the upper surface of the base is troweled or smoothed off, the strength of the bond is reduced; it is important, therefore, to leave the base free of troweling. It cannot be too strongly insisted that the top mortar be applied as quickly as possible after the concrete base has been tamped into position. It is frequently specified that the top finishing of concrete sidewalks shall follow immediately the concreting of the base, or be delayed not more than 30 minutes.

Care must be exercised to prevent sand or any other material from being dropped on the concrete base, and thus preventing a proper union with the wearing surface. Sometimes the base is permitted to become dusty and dirty by the dust being blown from the street and from careless workmen walking over the fresh concrete. Where sand or any other material falls upon the base it should be cleaned off and a coating of neat cement and water applied in a thin wash. Top finishing mortar will not adhere well to smooth, dry, unclean, oily or dusty surfaces. If the concrete has begun to dry it should be wetted just before applying the top mortar. Remove any dirty water that might collect on the top of the concrete base before placing top mortar.

The wearing surface should always be finished up to a joint. Under no circumstances must the top mortar be applied to a portion of a block and then some time allowed to elapse before applying the remainder. Sometimes an attempt is made to weld new mortar to that already set, but alternate freezing and thawing is likely to open a crack at the weld; and hence welding should never be permitted.

Do not use a base of one brand of cement and a top surface

of another; the difference in quality of the cement, in time of setting or hardening, contraction, expansion, etc., often causes top to crack from base.

Freezing of work done in cold weather will cause loose tops.

Placing Top Mortar on Hardened Base.—Where the work upon the top surface has been unavoidably delayed until the concrete in the base has set or hardened, or where it is desirable to place a new top mortar on an old base, special means must be employed to insure perfect adhesion between the top and base (see Art. 27). Two methods of bonding with success are:

(1) Care must be taken to remove all loose, inert or foreign material from the concrete base before any attempt at bonding the new work is made. The old concrete should be roughened up, swept and thoroughly washed with water. The base should then be rewashed with a dilute solution of muriatic acid or with an acid wash, such as "Ransomite." The acid wash loosens up any dust, dirt, woody matter or other foreign substances that may be present or embedded in the concrete, cutting slightly the surface film on the concrete, producing a surface not unlike that of coarse sand-paper, an excellent one for the adhesion of the top mortar. After the acid wash has worked, it must be removed as far as possible by thorough washing until every trace of acid and dirt is removed before applying the top finish. Any remaining traces of acid may be detected by tasting the water left on the surface. The top mortar should now be applied to the wet surface in the usual way. When the acid wash is not used on the concrete base, other means of preparing the surface may be resorted to, but probably with not so good results. The following method, however, has proved quite successful:

(2) The surface of the base should be thoroughly wet with water, and with a stiff broom or wire brush all dirt and loose material scrubbed from same. By a vigorous use of the wire brush (if the surface being treated will permit of it) the aggregate in the base can be uncovered; that is, the film of cement over same scrubbed or brushed off where it has not thoroughly set or hardened. By removing this film of cement (similar to the acid treatment mentioned above), the new mortar top can have every chance to bond with the base. After the concrete has been sufficiently brushed it should be again washed with water and grouted with thin cement mortar (see page 329). The top mortar should now be applied in the usual way before the grout has dried.

Placing top mortar on hardened base concrete should be permitted only in case of absolute necessity. The surface of the concrete in any case should be rough and all dust, dirt, oil, grease, embedded sawdust, woody matter, locomotive cinders, etc., removed, before any attempt at bonding top mortar to hardened base is made. After the surface has been properly prepared by either method mentioned above, the top mortar should be applied in the usual way. If considered necessary the acid wash treatment may be followed up by flushing the base with thin grout and this followed up immediately with the top finish. Mortar that fails to show a proper bond after

it has been allowed sufficient time should be taken up and replaced with new mortar of the proper quality.

Should it become necessary to delay the placing of the top mortar after several blocks or slabs have been laid, the work may be saved by the following treatment: Immediately after laying and while still soft, roughen the concrete base with a wire brush, thus producing to some extent a surface similar to that obtained by the use of an acid wash as mentioned above, thereby saving a great amount of labor later on when the concrete is hard and unresponsive. If this brushing is done carefully and without appreciably disturbing the concrete while green, the results will usually be satisfactory to a certain extent, although it may become necessary to resort to one or the other of the above mentioned methods of securing a good bond.

Surface Treatment.—After the top mortar has been pressed heavily onto the concrete base and the surface struck off with a straight edge as mentioned above, the character of the desired surface decides the next step. The usual practice is to float the surface, first with a wooden float and afterwards with a metal float or plasterer's trowel, the operation being similar to that of plastering a wall. The floating of the surface, however, is a point on which there are many opinions. Some prefer the use of a wooden or cork float entirely, while others prefer a glassy finish produced by the vigorous use of a steel trowel. The exact time at which the surface should be floated depends upon the setting of the cement, and must be determined by the builder. Considerable skill is required in troweling to prevent the formation of hair-cracks by over-troweling, and to insure a surface which will not wear easily as a result of insufficient troweling. Troweling for an excessively long time is very objectionable, since it is apt to work an excess of cement to the surface, a result which makes the walk more slippery and less durable.

Steel Trowel Finish.—While a steel trowel is universally employed in finishing the flat surface of walks, yet its use must not be carried to an excess. The general tendency when a steel trowel is employed is to use it too much, and over-troweling flushes neat cement to the surface and forms a thin, hard coating that seems all right at first, but which afterwards scales off, revealing a layer of almost clear sand. A similar result obtains if attempt is made to retrowel a surface once finished and partially set, but afterwards defaced. In other words, excessive troweling will form a film of clear cement over the surface of the work, and in drying this contracts and results in crazing or hair-cracks. Furthermore, the use of a steel trowel gives a glossy, streaked and cheap appearance to a sidewalk, which is neither good-looking nor practical. Also, a surface that is too smooth is not to be desired in walks, for the reason that when wet they are very slippery, and, besides, the smooth finish shows every little blemish and variation in color. There is constant danger of slipping on a glassy finish to a walk, especially if there is any considerable grade to it.

Wooden Trowel Finish.—A good finish can be obtained by using a

wooden or cork float, such as plasterers use, finishing with a revolving motion in the floating. The floating must not be done too heavily, so as to shove the mortar, but slightly, so as to compact the surface and at the same time give it an even, unmarked appearance. The wooden trowel finish is especially suited to severe northern climates, as it prevents pedestrians from slipping. It is growing in popularity, and certainly has many points in its favor. A rough finish is less expensive to lay, not requiring the time expended to make a smooth surface. Many cities are enforcing the wooden trowel finish to be made on all new walks laid.

Brush Finish.—Another finish to the surface is known as the brush finish, which is had by stroking in one direction with a moistened whitewash brush applied after the wooden float. The result is a good, even surface on which there is no danger of slipping, and which in appearance is equal to the best natural stone.

Special Tool Finishes.—Another method is to indent the surface. A small imprint or dot roller is used, the surface of which is covered with pointed studs that, in passing, indent the surface, giving it the appearance of having been bush-hammered. The flags or slabs after being trued up are marked all over, with the exception of a border of about an inch in width along the edges, with the roller.

Other Finishes.—When a rough surface is desired, the top is smoothed down and then some coarse, clean sand sifted over it. The troweler goes lightly over the surface to partially embed the sand. Another method is to float the top coat and then lay a piece of leather or rubber down onto the mortar. The sheet of leather or rubber is then peeled off the cement, leaving a roughened surface. Sometimes the surface is treated with acid to eat away the cement before it is fully set, so that the sand or screenings will appear and make the surface rough.

Precautions to Be Observed in Using Floats, Etc.—In using floats, tooth rollers, groovers, etc., it is important to frequently wet the tool, so that it will not catch in the cement finish. In case such should happen, or the tool slip while handling, some cement should be instantly dusted on the damaged part and sprinkled lightly with water, and the float or trowel used to finish smooth again, and the tooling or surfacing continued.

If the top surface is worked too long with the float the cement is brought to the surface, robbing the next lower layer of its cement and resulting in scaling. In troweling it is very important to consolidate the edges of the blocks. The general tendency to trowel the blocks low in the center must be carefully guarded against, as these depressions retain water after a rain and keep the walk needlessly wet. (See page 484.)

Dusting Top Finish.—Sometimes the top mortar is inadvertently made too wet, and an excessive amount of water appears in floating and troweling, particularly on a cool, damp day. Dusting the surface of the top finish, after placing, with dry material to absorb any free water that may have collected, should not be resorted to unless absolutely necessary. To take up this water, dry cement is sometimes

sprinkled over the surface; but this practice is very undesirable, since it is detrimental to the wearing qualities of the surface, producing indentations, pock marks and other defects. If the proper amount of water is used in the mixing in the first place, dusting will be unnecessary. The application of neat cement to the surface in order to hasten hardening should be absolutely prohibited under all circumstances. A surplus of cement makes the surface of the walk more friable than though the proper proportion of sand had been used. It will also cause the finished walk to have a mottled appearance, or cause small hair-cracks, owing to the dry cement forming little balls of neat cement mortar when coming in contact with the water, and on being troweled out will show spots and hair-cracks.

The best method of removing any free water that may have collected on the surface is to absorb it with the same proportions of dry ingredients as the top finish itself, which are usually about one part of Portland cement to two parts of sand, and then there will be no excess of cement and no spottedness.

A mixture of hydrated lime (see page 428) and marble dust, in the proportions of 1:2, is sometimes used as an aid in correcting the detrimental effect of flushing too much cement to the surface by the action of the steel trowel. (See page 484.)

It is the practice of some workers to add a dry mixture to the surface of the top mortar in finishing in order to produce a white color or a colored surface. (See page 391.)

Conditions Governing Shade or Color of a Walk.—A sidewalk finish frequently presents a patchy or unsightly appearance—in fact, it is not such an easy matter to secure a uniform shade or color throughout the walk. The lack of uniformity of shade or color in the same walk is much more noticeable than the lack of uniformity of shade or color in abutting walks. The variations in the shade or color of a finished walk are usually due to one or more of the nine well-known causes which may be summed up as follows:

1. Variations in the nature of the cement and sand or stone screenings.
2. Lack of uniformity in the amounts of cement and sand in each batch of mortar.
3. Insufficient mixing in any or all batches of mortar.
4. Consistency of the mortar.
5. Amount of troweling.
6. Character of the finishing tool used.
7. Time which elapses between placing and finishing the top.
8. Weather conditions and temperature.
9. Treatment and protection which the work receives during the first 48 hours after completion.

Different materials will give different results. No change in the brand or quality of cement should be made while laying the top mortar. Different brands of cement may give different colors to the finished walk. If more than one brand is used, the colors must be such as not to show marked variations in appearance of the walk.

All sand should be of a bright, uniform color. No sand should be used which contains small particles of coal or lignite. The water used in mixing the mortar should be free from iron or other impurities that tend to discolor the mortar. (See page 378.)

Although the builder may be so fortunate as to always obtain the same grade of materials, he will find that uniform results are equally dependent upon proper methods of mixing and applying the top mortar and upon careful workmanship. Lack of uniformity in the amounts of ingredients in each batch will cause imperfections in the exposed surface of mortar. The inspector should make certain that the specified proportions are accurately and uniformly adhered to. (See Art. 14, page 152.)

Mortar should be thoroughly mixed and not allowed to look raw when deposited on the concrete base. If the mortar is not uniformly mixed, the surface will be irregularly colored and will contain pitted and honey-combed spots. Variable proportions of water should be avoided. (See Art. 15, page 161.)

A mortar mixed dry gives a darker finish than a wet one.

The opposite sides of a stretch of walk will frequently appear to be of different shades, as the result of half of it being finished from one side while the other half was finished from the opposite side.

The character of the finishing tool used in troweling the surface will affect the color or shade of the walk to some extent. A steel trowel gives a darker finish than a wooden trowel or float.

If the top mortar is allowed to become too dry after being floated, and then finished with a steel trowel, it is apt to contain blotches which remain indefinitely.

Weather and temperature conditions sometimes affect the color or shade of a walk. The author has observed walks which had been laid either in the late fall or spring, of two different shades, according to whether they were in the sunshine or shadow. Walks affected in this manner, however, usually bleach out in time, but until this occurs the appearance of the walk is not pleasing. Of course, such conditions are beyond the builder's control. The author simply mentioned this to show how sensitive a sidewalk finish is to the treatment it receives.

A walk allowed to harden under a wet sand covering tends to bleach out lighter in color than one which is exposed to the air during the hardening period. Fresh manure placed over very green top mortar to protect the walk from freezing is very apt to discolor the walk. (See page 361.) Dirty water dripping from tarpaulins or paper used for covering will cause a non-uniform color and streaks in a walk. (See page 380.)

Colored Wearing Surfaces.—The wearing surface is frequently colored, or some squares are left the natural cement color and alternate squares of a different color, so as to give a contrast and avoid a sameness in the sidewalk. If a colored surface is desired, the coloring matter should be mixed with the whole of the top mortar. For the most permanent results, naturally colored aggregate should be employed. When colored sand or other material is not available,

artificial coloring matter may be employed to give the desired shade. Don't use artificial coloring matter containing oils, grease or acids, for they lessen the strength of the cement. Only those coloring materials should be used which consist of the oxides of the various elements, since salts are liable to disintegrate. The disadvantage in employing artificially colored mortars is the fact that they cannot be assured to hold the same shade for all time. In fact, most coloring substances are bleached by the cement and are of short life.

The following proportions are suggested, the amounts named being added to a bag of Portland cement containing about 95 lbs.:

Black—2 lbs. Excelsior carbon black.
Blue—5 lbs. Prussian blue.
Gray—1 lb. Germantown lampblack.
Red—8 lbs. raw iron oxide.
Yellow or Buff—9 lbs. ordinary yellow ochre.

Germantown lampblack is more frequently used than any other coloring matter, and gives a bluish gray or stone color of intensity varying with the amount used. (See page 396.)

The coloring matter should always be mixed with the dry cement, and the two in turn mixed with the sand before adding water. In mixing the ingredients the greatest care and exactitude are essential. If improperly mixed, the surface is apt to be spotty.

It is the practice of some contractors to color only the surface of the walk instead of the entire top mortar, as mentioned above. There are several ways of doing this. One method is to add the coloring matter to a mixture of cement and sand of the same proportions as that used for the wearing surface. This mixture should be sprinkled very evenly over the wearing surface after it is in place and the surface then floated and troweled in the usual way. It will generally be found necessary to repeat this treatment two or three times, until the desired shade is obtained. The wearing surface must be mixed a little wetter than otherwise, so that the dry colored mortar may be properly worked into the wearing surface. This method of coloring the surface is not so good as that of introducing the coloring matter directly into the top mortar as mentioned above, since the coloring matter is likely ultimately to wear through and leave the walk spotted. Results of this method of coloring the wearing surface are to be seen in a number of places.

Another method of applying the coloring matter is to sift or sprinkle it over the surface, and then to trowel it in. This is an exceedingly poor method and should not be permitted, since the coloring matter is easily blown away. The walk is very likely to be spotted or to wear so, and also to flake off in places where there is an excess of coloring matter.

Sometimes a very white walk may be required. White cannot be produced by adding a coloring matter. To secure a white walk, the surface may be sprinkled with white Portland cement and white sand or powdered white marble, mixed in about equal parts and

used with a sieve, the surface being troweled in the usual way. Care must be taken to keep the surface of the walk free from dirt or dirty water. Another mixture is to employ ordinary Portland cement, hydrated lime, and marble dust or white sand, mixed in the proportions of 1:1:2, and sprinkled lightly over the surface with the aid of a sieve, then finished with the trowel in the usual way.

Marking or Blocking Wearing Surface.—There might possibly be some chance for argument regarding the proper surface treatment which a walk should receive, but certainly the marking of the wearing surface into blocks will not permit of any. Preserving joints in the concrete base of walk has already been mentioned (see page 476). These are the real joints and the markings in the top should always occur over them. Care must be taken to see that the top mortar is cut entirely through on exact line above the joints in the base. This may be done by a trowel working along a straight edge, after which the edges are rounded off with a special tool called a jointer, having a thin, shallow tongue. In cutting the top mortar the trowel should be held to cut, and thus avoiding dragging and tearing the edges. Special tools may be had for cutting through the mortar and rounding the edges of the joint at one operation. The cutting is often indifferently done, and sometimes the cut through the wearing surface is not directly over the cut through the base. Then if there is any settlement the top will crack in an irregular line.

The marking is sometimes done by means of a chalk line stretched between the ends of the desired mark. This line is then pressed into the softer mortar with a small trowel, and, being removed, leaves the mark. A trowel or special tool is then used to cut the mortar through to the base, following the mark made by the chalk line, and the joint finished by a grooving tool, which leaves a rounded edge.

Oftentimes, through carelessness, the joint in the mortar is not in line with the under joint. It cannot be too strongly insisted that marking of the wearing surface into blocks shall be directly over the block joints in the base. If this is not done the mortar or top surface will check across even with the lower joint, thus impairing the work. Under such circumstances zigzag cracks will appear from $\frac{1}{4}$ to 1 in. from the joint line shown on the surface. Water will also get in at the joint under the top mortar and freeze, causing it to break. More walks are disfigured by failure to provide proper joints than from any other cause. The inspector must see that the marking is done with a tool which cuts clear through to the base. Joints must be continuous to prevent cracks from running into adjacent slabs.

Finishing Edges of Walk.—A trowel should be run along side forms as far as finished, cutting about 1 in. deep, and held in such a way as to crowd the mortar back from the form about $\frac{1}{8}$ in. The edges of the walk are now finished by placing a quarter-round tool into the trowel cut and sliding the same along the side form for the whole length finished, repeating the operation on the other side. Care must be taken to press only hard enough to make an even and straight furrowed edge. The edges are generally rounded off to a curve of

about ½ in. radius. An edging trowel, which is a small float with one of its edges curved, gives a good finish. The outer edges are sometimes beveled.

Workmanship.—The finished surface should be hard and dense and free from any defects of workmanship, such as depressions, elevations, etc., and should conform to the proper grades. In other words, the finished walk should show an even, true surface, free from sags, humps, pits or other defects. The troweling should be done so that if a four- (4) foot straight edge is laid in any direction upon the walk a space greater than ⅛ of an inch will never be found under it, and seldom a space greater than 1/16 of an inch will be found. A certain specification in the author's possession requires that when a straight edge five (5) feet in length is laid upon the surface at any point, except at grade changes, the surface should at no point vary more than ¼ of an inch from the true edge of the straight edge.

Before the final release of the work all concrete sidewalks should be carefully inspected and sounded for defects, and any hollow or otherwise defective blocks should be cut out. Relaying of top course only, should not, as a rule, be permitted. (See page 445.)

CARE AND PROTECTION

After the surface has been finished the walk is left to harden. Care must be taken to prevent it from the elements and traffic until it has set. (See Art. 29, page 335.)

Protection from Rain.—The finished walk must be protected from the direct impact of rain while it is still soft. Rain falling on soft mortar washes and pits the surface, making it rough and unsightly. Any covering that will prevent the direct impact and wash of the rain on the green mortar is satisfactory. This can be accomplished by covering with roofing paper or canvas.

Protection from Sun and Wind.—Cracking may be caused by the upper surface of the walk drying out faster than the bottom, acting very much as dried mud in a river bottom, where the sun dries the top first, which shrinks and breaks up into small blocks. Subsequent shrinking in the lower stratum only increases the width of the cracks. For this reason the surface coat must be protected from the hot sun, after placing, to prevent too rapid drying, which weakens the mortar and causes hair-checking or map-crazing. A strong warm wind blowing over top-finish mortar while soft is very apt to check it. In other words, if the surface of the setting cement is not protected from the direct rays of the sun, cracks will generally be produced.

Various methods of protecting sidewalks from too rapid drying are available. Some contractors employ sand as a protection, placing it where the walk is hard enough so as not to injure same, removing it when the walk is thoroughly hardened or fully cured. The sand should be of sufficient depth, generally ½ in. will answer, and should be wet thoroughly with a hose nozzle as often as may be necessary. Sawdust, shavings, straw, grass, cloth, paper, etc., are other means

of covering that may be adopted. Freshly cut grass answers very well when it can be had, though anything that will absorb water and can be sprinkled without removing can be used.

Curing Sidewalks.—There is a considerable variation in the expansion of lean and rich mortar when alternately wet and dry. For this reason the base and top should be kept in the same wet condition long enough to make sure that the chemical and physical changes which cause the bond have an opportunity to become complete. This requires plenty of moisture for some time. However, do not put water on the sidewalk until it has set hard, usually after 12 or 18 hours; then it becomes very necessary to keep the walk wet thoroughly and continuously for as long a time as economy will permit. Sprinkling the surface before the cement has thoroughly set may cause blisters, which mar the work. (See page 348.)

Too much importance cannot be attached to the curing of walks, as in the rapid drying days the set or hardening of the concrete will be unduly hastened, with a decrease in the strength of the work. The surface should be covered with any of the coverings mentioned above, for at least the first 12 hours on such days, and then by wetting the work well twice a day for several days the material will be given a fair chance to attain the maximum strength and durability. Concrete sidewalks after setting up can hardly have too much water, provided the water is not dashed on while the surface is hot from exposure to the sun nor while still too soft to resist the washing action of the water. Water is a very important element in the curing of all cement work. Sidewalks should be kept covered for a week and constantly wet. They should not be allowed to dry for a moment at any time during the first week. It is known that wetting the surface will also produce a whiter walk than one that is allowed to dry out quickly.

Protection from Traffic or Accident.—Special care must be taken to protect the walk at night. It should be fenced off so that animals may not walk over it while still fresh. This applies especially to dogs and cats, which have disfigured many an otherwise good walk. These barricades should be at least 3 ft. high at each end of the walk. On the sides of walk the same or other kind of sufficient barricade should be used to protect the walk from injury and guard the public against accident. All barricades should be properly protected by red lights at night. If necessary, keep a man in charge to keep animals and persons from walking over the newly laid walk.

The walk may be opened to light travel after about four days, but it is better to remain covered with damp sand, grass, etc., for a week or two, to prevent wear while tender.

Protection from Frost.—Sidewalks should not be constructed during cold weather unless unavoidable. Where work is placed in freezing weather, the surface can be covered with sand, and upon this manure can be placed, with a covering of canvas or tar paper to prevent the rain or snow falling on the manure and thus leaching through to the concrete. Fresh manure must never be applied directly to the walk, or the mortar surface will be discolored by the manure

as well as injured by the ammonia in same. If construction in freezing weather is unavoidable, the rules given previously for concreting in freezing weather should be carefully followed. (See Art. 33.) In freezing weather the same precautions as to heating the aggregates, etc., are necessary as in other classes of concrete work. The covering should remain on walks laid in freezing weather for at least three weeks.

CLEANING UP AFTER COMPLETION OF WORK

Cleaning Up.—After the walk has been completed the street in front of same should be cleaned of all surplus material, cement, sand, broken stone or gravel, barrels, etc., used in its construction.

Grading.—The slopes and parks should be graded to conform to walk and curb grades (or to lines indicated on the plan) and dressed with fine earth, raked and left smooth. Grading on the curb side of the walk should generally be about an inch lower than the sidewalk, and not less than one-quarter ($\frac{1}{4}$) inch to the foot fall towards the curb or gutter. On the property side of the walk the ground should be graded back at least 2 ft. and not lower than the walk. This will insure the frost throwing the sidewalk alike on both sides.

Sodding.—If sodding is specified, the lawns may be sodded with bluegrass sod, free from weeds. All joints should be broken in laying and the sod laid to a uniform and even surface. The sodding should be kept sprinkled until such time as the entire improvement may be accepted. If the lawns are already in grass they should be left in proper condition and any unnecessary damage should be repaired.

Seeding.—Parks may be sowed with white clover seed of good quality, using one pound of seed for each three hundred (300) square feet.

Art. 52. Concrete Curbs and Gutters

Closely connected with concrete sidewalk construction is the matter of providing concrete curbs and gutters. Curbs are usually 6 to 8 in. wide and 12 to 18 in. deep, 6 to 8 in. of which extends above the surface of the roadway. Gutters are usually 2 to 3 ft. wide, sloping towards the curb, and have 7 or 8 in. of concrete overlaying a sub-base.

Most of the general and specific instruction to be followed in inspecting concrete sidewalks (see Art. 51) is applicable to either concrete curb or combined curb and gutter construction. In other words, the construction of curbs and gutters should follow the same principles as to excavation, fill, concreting, finishing, etc., as outlined for sidewalks.

Concrete Materials.—The cement should comply with the Standard Specifications for Portland cement of the American Society for Testing Materials, adopted June, 1904, together with subsequent changes and amendments. (See also Art. 4, page 43.)

The sand, broken stone or gravel, and water for concrete should

conform to the requirements stated for sidewalks. In this connection, see Chapter II, page 70. It is sometimes specified that no gravel greater than 1 in. in diameter shall be used. The inspector will, of course, be governed by the specification requirement as to the size of aggregate.

Sub-Grade.—The excavation should be made to the sub-grade previously determined upon, which should be of sufficient depth so as to get below frost.

The necessary grading for preparing the base or sub-grade and compacting it to render it suitable for curb and gutter construction should be carefully done. It is sometimes required that sufficient grading be done in each case to leave a backing of at least 5 ft. in width back of it, and on a level with the top of the curb, such filling being compacted and sloped down to a solid base on a slant of one and one-half to one.

All soft, boggy, spongy or defective places should be removed and all depressions filled with suitable filling material, which should be thoroughly compacted by flooding and tamping in layers not exceeding 6 in. in thickness.

When the sub-grade occurs on fills exceeding 1 ft. in thickness, its preparation requires very careful attention. In all cases fills must be thoroughly compacted.

Sub-Base.—Upon the sub-grade prepared as above, and after inspection and acceptance of the same, should be placed a foundation of compacted coarse sand, cinders and other suitable material as mentioned for sidewalks, of not less than 6 in. in depth, such sand, cinders, etc., to be free from earthy and other objectionable materials. The sub-base may consist of a layer of broken stone or gravel 6 in. thick, or 6 to 12 in. of cinders, thoroughly rammed. Tamp well and evenly, and thoroughly drench the cinders, gravel, etc.

The preparation of the foundation should be similar to that required for a sidewalk, care being taken that the sub-base be thoroughly drained, the drainage system being connected with sewers or other drains as may be indicated on the plans.

Forms.—After the foundation or the top of the sub-base has been brought to the proper distance below the grade stakes, forms are placed for the curb or the combined curb and gutter, being of such shape and dimensions as may be required. These forms should be held in place by stakes set by an engineer at points necessary to accurately designate the line and grade of the proposed curb and gutter.

The material for forms should be $1\frac{1}{2}$ to 2 in. stuff, dressed on the edges and on the side next the concrete. Special metal forms may be employed.

At least once in every one hundred and fifty (150) feet, expansion joints should be provided, these joints to be constructed as specified or as may be required by the engineer.

Concrete Body.—After forms are in position and have been carefully inspected, the concrete base should be deposited.

Materials for the concrete body of curb, or combined curb and

gutter, should be proportioned according to the voids in the aggregates, not exceeding 1 part Portland cement to 8 parts fine and coarse aggregates. When the voids are not determined the concrete should be composed of 1 part Portland cement, 3 parts fine aggregate and 5 parts coarse aggregate.

Materials should be mixed wet enough to produce a concrete of such a consistency that it will flush readily under a light tamping and which can be handled without causing a separation of the coarse aggregate from the mortar.

A layer of concrete should be deposited to the top of the gutter formed and tamped, the width of the gutter, to a surface all points of which should be at least the thickness of the wearing surface below the finished surface of the gutter. Concrete placed for the curb should be tamped and the remainder of the concrete placed and tamped to permit of the application of the required wearing surface to the face and top of the curb.

In constructing curb or combined curb and gutter, particular attention must be given to have all templates perpendicular between the stones. All stones should be of uniform length, of about six (6) feet, and should be separated from each other by a 1/4-in. sheet of steel templates made to conform with the shape of the curb or combined curb and gutter, which are to be removed after the cement has sufficiently set. Fill in the cuts thus formed with dry sand.

Finishing or Wearing Surface.—Immediately after the completion of the body course, and before the cement therein has had time to set, the finishing or wearing surface should be added.

The mortar for the finishing surface should be composed of 1 part Portland cement and not more than 2 parts of fine granite, flint or slag screenings of a size not exceeding that of ordinary coarse bank sand, and it should be free from all foreign materials. The consistency of the mortar should be such as will not require tamping, but which can be easily spread into position.

The gutter should be sloped to meet the requirements of drainage by increasing the thickness of the top coat on the side nearest the street. Work to an even surface with a straight edge laid parallel with the curb.

Wearing surface on the gutter and on the top and face of the curb should be at least 3/4 in. thick.

Edge of the curb on the street side and the intersection of the curb and gutter should be rounded to a radius of about 1 1/2 in., all other edges to have a radius of about 1/2 in.

All exposed surfaces should be carefully finished by troweling to a smooth and even finish, and must be left free from irregularities and depressions. Do not let too great an interval elapse between floating and troweling. Use a curved trowel for top corners of curb and angles between curb and gutter.

After troweling, finish with a soft brush; an ordinary hearth brush or whitewash brush will do. If the top is too dry, sprinkle with water. The brush will take out the trowel marks and give an even texture and color to the finished work.

The wearing surface should be cut directly over the cuts made in the concrete base, leveling the edges of the cuts with a jointer.

An excellent finish may be obtained by taking the forms down within 24 hours and rubbing the surface with a cement brick made 1 to 3, instead of using a brush as mentioned above. The brick should be formed so as to fit in and around the corners. When rubbing, use wet sand. This will polish the surface and remove all marks of the forms, also any efflorescence (see Art. 31), and prevent hair-cracks and crazing.

Any spalling or splitting off whatever of the finished surface, either at the joints or in the body of the section, should be sufficient cause for rejection. No patching of any character should be allowed.

Protection.—When completed, the curb and gutter should be kept moist and protected from traffic for at least a week. In other words, protect the work as previously described under Sidewalks.

Art. 53. Concrete Pavements

Most of the general and specific instructions to be followed in inspecting concrete sidewalks, as stated in Art. 51, are applicable to concrete street pavement construction. In this case, however, even greater care must be taken to see that the pavement is monolithic from top to bottom, so that there can be no separation of layers.

Concrete for concrete pavements must be more thoroughly mixed and of higher grade than is necessary in any other form of concrete construction.

Concrete Materials.—The cement should comply with the Standard Specifications for Portland cement of the American Society for Testing Materials, adopted June, 1904, together with subsequent changes and amendments. (See also Art. 4, page 43.)

The sand should be clean, coarse, and of good quality, free from all foreign matter except clay, which may be permitted if the quantity does not exceed 5 per cent, and provided it does not occur as a coating on the sand grains. The sand should all pass a No. 4 mesh. The screenings, all of which should pass a No. 4 mesh, should be crushed from clean, sound, hard, durable rock, and should be clean, dry, well graded and free from excessive dust, which should not occur as a coating on the particles of stone.

The coarse aggregate may consist of broken stone, gravel, broken brick, burnt clay ballast, slag, clinkers, chats, and, in fact, any good firm material that is able to stand exposure to the weather without breaking down, that will not melt or be readily attacked by moisture or acids. It should be so broken or screened as to be retained on a one-quarter (¼) inch mesh, and pass in any direction through a one and one-quarter (1¼) inch mesh. The broken stone should be from clean, hard, sound, durable stone, and should be as nearly cubical in shape as possible; the gravel of good quality; the crushed slag from hard, dense, blast furnace slag, etc.

The aggregate should be graded as uniformly as possible to the

sand grains. Well-graded gravel forms one of the best aggregates that can be used for concrete pavements. If crushed stone is used, the screenings should be retained in the stone unless they are of such a character as cannot be well used in the place of sand. Only hard material absolutely sound and free from all soft particles should be in the aggregate.

Care should be taken that careless workmen do not get dirt into the stone and sand in handling it on the street.

Stakes.—The inspector should consult with the foreman as to when lines or levels will be needed, and arrange to get word to the engineer about two days ahead, so that the work will not be delayed on account of prior engagements of the field parties.

Grading.—The preparation of the surface of the earth for the laying of the pavement is practically the same as that required for sidewalks, as described on page 467.

The entire width of the roadway should be graded to the proper sub-grade to permit of the specified thickness of paving materials being laid to bring the finished surface of the pavement to the lines and grades as established by the engineer; the bottom of the excavation or top of the fill, when completed, being known as the sub-grade.

The sub-grade when properly compacted should be parallel to the finished surface of the pavement—that is, all slopes, elevations for crossings, etc., should be produced in and formed by the sub-grade. The ground must be formed carefully to the contour of the finished surface. Care must be taken to see that the sub-grade is at the proper distance below the finished pavement equal to the amount required by the specifications.

All soft, spongy or yielding spots should be dug out and refilled with good, clean, hard material, such as broken stone, gravel, etc. All vegetable or perishable matter must be entirely removed from the sub-grade.

Fills required to bring the sub-grade to the proper elevation should be made in 6-in. layers, and each layer should be thoroughly tamped or rolled.

Where poles are to be moved, pipes to be lowered, valve boxes to be readjusted, conduits rebuilt or work of like character encountered, the inspector should make out a complete statement (usually on special blanks provided for that purpose), giving exact location and name of company, whether gas, telephone, telegraph, water-works or otherwise, and hand to or mail to the engineer as soon as stakes are set. The engineer will then notify the company by letter. The inspector should give these companies a reasonable time to satisfy the city's demand, after which notify the engineer again in the same way, and not the companies direct. The failure of such companies to remove the obstructions promptly does not warrant the rooting up of pipes or chopping into poles.

Sub-Grade.—The sub-grade should be brought to a firm, unyielding surface by means of heavy rollers and tampers. The steam roller should weigh not less than 10 tons, and the hand-tamper should be about 10 in. in diameter and weigh not less than 50 lbs. The rolling

should be carefully and thoroughly done, and care should be taken to get all sewer, water and gas pipe trenches well rolled and solidly packed.

The inspector should satisfy himself that the sub-grade is dressed to the correct depth and crown as shown on the cross-section, and kept in shape. To insure the grade being at the proper elevation it should be tested with a street gauge, and any imperfections corrected. It is important as a matter of economy in construction that the sub-grade be prepared carefully and truly to cross-sections and grades, so that additional concrete, which is expensive, need not be employed in filling up depressions and uneven places on the sub-grade; but it is better that the sub-grade be a trifle too low than too high, in order to avoid thin places in the concrete from the latter cause.

Where considered necessary or of assistance in producing a compact, solid surface, the sub-grade should be thoroughly sprinkled with water applied through a hose provided with a sprinkler nozzle.

The sub-grade should be so thoroughly compacted by rolling and tamping that a wagon with 2-in. tires loaded with 2 tons of material can be drawn over it without making an appreciable indentation. This applies to a clay or heavy soil. When the material is sandy or gravelly, such hardness in the rolled surface cannot be obtained. No allowance for compression in rolling should be made on hard, dry, clay soils.

In grading where sands and gravels which do not hold water are encountered, the pavement may be laid directly upon the properly prepared sub-grade, as mentioned for sidewalks; but upon a foundation of ordinary dirt, clay or loam, a suitable sub-grade as hereinafter mentioned should be used.

Sub-Base.—If the sub-grade is sandy or gravelly, the concrete base of the pavement can rest directly on it. In clayey and other water-holding soils, however, there should be a 6 to 10 in. sub-base of cinders, slag, gravel or broken stone, the material ranging in size from ½ to 4 in. This sub-base is placed to minimize the danger from frost.

All fills in the sub-base should be made in thin layers, well moistened and rolled with a steam roller to a firm, unyielding surface that does not "wave" in front of the wheels of the roller. Where the thickness of the sub-base exceeds 6 in. it should be laid and rolled in two layers of equal thickness. For a monolithic pavement, such as concrete, this perfect preparation of the sub-base is of great importance, and extra care must be used in every instance. The sub-base must be rolled to a uniform surface, parallel to the final roadway and at the proper distance below same.

The use of proper material in the sub-base and careful compaction of the same are often neglected. A concrete pavement widely distributes the load brought upon it, and while pockets in the sub-base may be bridged by the use of concrete, they may become of such size as to cause failure. Therefore, the sub-base must be prepared in such a way as to avoid the formation of pockets.

Before laying the concrete base the sub-base should be well

sprinkled with water applied through a hose fitted with a sprinkler nozzle.

Before laying the concrete base the sub-base should be well sprinkled with water applied through a hose fitted with a sprinkler nozzle. The amount of water needed varies with the character of the soil. Unless the sub-base is wet, it may absorb enough water from the concrete to prevent its setting properly.

Drainage.—Drainage should be provided for in all cases where natural drainage does not exist. The artificial drainage system should be constructed and connected with the sewers or other suitable outlet, as may be directed by the engineer. The inspector should see that the drain tile is cemented into the outlets (if so required) and should replace any broken by rollers or stakes.

If the pavement is a country road, either a tile or a French drain should be provided along the sides, when in the judgment of the engineer the same is necessary. The bottom of the said drain should be at least 12 in. below the crown of the sub-grade. The outlet and lateral blind drains should be provided as indicated by the engineer. Surface water should be taken care of by side ditches of sufficient capacify to insure proper drainage. Side ditches should have sufficient fall to carry the water quickly to the adjacent streams and not allow it to stand in pools along the sides of the road.

Shoulders.—When the concrete pavement is not abutted by a curb and gutter, there should be provided instead a shoulder of gravel or broken stone of a thickness at least equal to that of the pavement and of a width of at least 3 ft. These shoulders should be thoroughly rolled and compacted and should be given a transverse slope away from the pavement of not less than 1½ inches for each foot of width.

Under such conditions, the edges of the pavement should be so sloped as to form a beveled joint between the pavement and the shoulders.

Cover Castings.—The inspector should see that valve box and manhole castings are not only to grade but to the proper slope of the crown.

Curbing.—The inspector should keep memoranda of the place and length of all curb redressed or reset. If possible, get all old curb reset together in the same block from which it was taken. The inspector should not order out old curb without orders from the engineer.

Circle Curb.—In case the plans do not show details of circles on slant corners, or ogees on offsets, the inspector should apply to the engineer for the necessary information.

Measuring and Mixing.—The fine aggregate and the coarse aggregate should be measured in suitable bottomless measuring boxes as mentioned on page 156, or by equally accurate devices. Measuring material by wheel-barrow loads or shovelfuls should not be permitted under any circumstances. See Art. 14, page 152.

A batch mixer should be used (see page 171). The ingredients of the concrete should be mixed to the desired consistency and the mixing should continue until the cement is uniformly distributed

and the mass is uniform in color and homogeneous. Whenever possible, the concrete should be deposited directly from the mixer to position without rehandling.

When it is necessary to mix by hand (see page 176), the cement and fine aggregate should be mixed dry on a water-tight platform until the mixture is of a uniform color. For the wearing surface, the water should then be added and the mixing continued until the mortar is of a uniform color and homogeneous. For the base, the required amount of coarse aggregate and water should be added and the mixing continued until the mass is of uniform color and homogeneous.

Care should be exercised in the amount of water used. A few experimental batches, mixed with varying quantities of water, will determine the proper amount. Then be sure that the proper quantity is used by having the water measured for every batch. The methods, too often employed, of dashing a promiscuous number of bucketfuls over the mass, or of adding water with a hose connected to the water main, are a little easier, but are sure to result in concrete lacking in uniform density and strength.

Concrete should not be mixed or deposited when the temperature is below freezing. If at any time during the progress of the work, the temperature is or in the opinion of the engineer will be within 24 hrs. below 35° F., the water and aggregates should be heated and precautions taken to protect the work from freezing for at least 5 days as mentioned in Art. 33.

Forms.—Forms along the sides of the pavement are desirable not only to confine the concrete and to fix lines and grades as mentioned on page 472 for concrete sidewalks, but are the most available tracks to support bridges from which the finishers may work. With this weight on them, it is necessary to make them substantial and to stake them securely. Curbs along the sides of a street serve the same purpose. By using a template, cut to the proper curve of the crown and resting on the side forms, a wavy surface is avoided. (See page 475.)

Pavement Proper.—In general, two methods of laying concrete for pavement purposes have been followed. One, where the material is put on in two layers, the lower material acting as a base, and the upper material being made richer to act as a wearing surface; and the other, where the concrete is made of the same consistency throughout and put on in one layer. In two-course construction the pavement should be made of a 4 to 6 in. concrete base and a $\frac{3}{4}$ to 2 in. wearing surface, depending upon the extent of the traffic.

Concrete Base.—Upon a properly prepared sub-grade or sub-base as mentioned above should be deposited the concrete base of the pavement. This concrete may be composed of Portland cement, sand or stone screenings and an aggregate, either broken stone or slag or screened gravel as mentioned above.

The concrete should be mixed in proportions of about one sack of Portland cement to three (3) cubic feet of sand or screenings, and five (5) cubic feet of coarse aggregate.

A wet mixture should be used for the concrete base, but not so wet that it will creep toward the curb or sag out of place when deposited and lightly tamped. The concrete should be very quaky and, in fact, should flow readily, but should not run like thin milk. It should be like a sticky, heavy cream.

The concrete base should be deposited across the entire roadway as soon after mixing as is practicable. In no case should more than thirty minutes elapse between the mixing and depositing of the concrete base. Retempering of the concrete base should not be permitted.

Each day's work must be a monolith. The spreading and the ramming should be so done that each successive batch will be rammed before the preceding and the adjoining batches have begun their first set. The concrete must be solid, not porous. Careful or thorough tamping must be insisted upon. The stiffness of the concrete after tamping in place must be such that the fresh mass will retain its form and will not crumble when the boards are removed preparatory to filling the adjoining space. Properly managed, there will be no lines between the batches, which will all be merged into one mass.

If, for any cause whatever, even at noontime, it is necessary to stop work, place a form across the street or road, and complete the work to this form. When this is not done, an irregular line of weakness is formed where batches join, and cracks are likely to develop.

The concrete should be well tamped to the proper surface below the finished surface of the pavement, as required by the specifications, with 8-in. hand-tampers weighing at least 20 lbs. each.

The placing of reinforcing material, if any, should immediately follow the tamping of the concrete base and should be tamped into the base enough to hold it there, and the top course or wearing surface should be placed immediately.

Expansion joints should be provided at the curb line ¼ in. wide, and every 50 ft. across the street ½ in. wide, formed by means of wooden or metal strips set in place. These are removed and replaced by paving pitch as mentioned on pages 478 and 502.

Wearing Surface.—The wearing surface should be placed at the same time or immediately following the concrete base, so as to make one solid layer. It should be put in place within thirty minutes after the base has been placed, if possible, but under no circumstances should it go on after an hour. The construction of the wearing surface is the most critical part of the work, for upon it depends the durability of the pavement.

The wearing surface should not be less than **¾ in. thick.** The usual thickness is from 1 to 2 in.

The best aggregate is crushed granite or trap, or a mixture of this and sand. Screenings should be coarse and well graded from approximately the size retained on a No. 40 mesh to the largest size passing a No. 4 mesh. One-quarter (¼) inch crusher run screenings or screenings containing more than five (5) per cent of material

passing a No. 40 mesh screen should not be allowed. Clean, coarse, well-graded, hard, siliceous sand may be, at the option of the engineer, substituted for screenings. Such sand should not contain more than ten (10) per cent of material passing a No. 40 mesh.

The wearing surface may be composed of one (1) part of Portland cement to one and one-half ($1\frac{1}{2}$) parts of stone screenings or sand. Some engineers prefer to use proportions of about one part cement to one and one-half parts sand to two parts of crushed screenings.

The materials for the wearing surface should be thoroughly mixed, first dry and then wet, either by hand, in a suitable mortar box, or in a batch mixer (see Art. 15). The mortar should be of such a consistency that it can be floated into place with a straight edge without tamping, and it should be deposited on the base within thirty (30) minutes after mixing, or before it shows any tendency to harden.

A thin mortar coat of neat pure cement mortar is sometimes spread over the base to a depth of about an eighth of an inch and the wearing surface then put on.

The wearing surface should be floated with wood floats, as steel floats produce too smooth a surface, and brushed with stiff vegetable fiber brushes or brooms before completely hardened. The surface may be left in this condition, or, after floating but before brushing, it may be marked off in rectangular blocks by grooving, in order to provide good foothold for horses.

Sometimes the surface is not floated but the topping is put on and tamped somewhat, after which it is swept with a very coarse broom.

Occasionally the surface is treated with acid to eat away the cement before it is fully set, so that the stones will appear and make the surface rough.

Sometimes, after the wearing surface is on and before it is set, a covering of pea gravel is put on and rolled in with a lawn roller.

When the surface is grooved the grooves should be approximately $\frac{3}{8}$ in. deep and $\frac{1}{4}$ in. wide, with the edges neatly rounded to prevent chipping or spalling. The blocks should be about 5x10 in., with the 10-in. dimension perpendicular to the axis of the street. At street intersections for a pavement with a grooved surface the area between the crossings should be marked into blocks about 5 in. square by grooves as mentioned above, but in this case making an angle of 45 degrees with the axis of the street.

Before final hardening the wearing surface should receive treatment with stiff brooms to eliminate what may otherwise be objectionable smoothness. After troweling, an ordinary street broom is usually drawn over the surface lightly from curb to curb to roughen it slightly.

One Course Construction.—The concrete should be mixed in proportions of about one sack of Portland cement to two (2) cubic feet of sand or screenings, and four (4) cubic feet of coarse aggregate. It has been fairly well established that the leaner mixtures—1:3:6,

1:3:5—are not satisfactory in one course concrete pavement work. The present practice (November, 1912) of the Illinois Highway Commission is a mixture of 1:2:3½.

Each batch of concrete as deposited in the pavement should be carefully watched by the inspector, that the mortar does not flow to the edge of the pile and leave a core of aggregate unsupplied with sufficient mortar. At least one workman should be assigned to shovel all such cores of aggregate to the bottom of the concrete layer, so as to insure only cement rich in mortar at the surface. If this is not done, depressions are very apt to develop in the surface under traffic, which is likely to loosen the clusters of pebbles of the aggregate, which do not have sufficient mortar to hold them fairly in place. The men finishing the surface should be warned not to let such places go by them without shoveling out the pebble clusters and replacing them with a richer mixture. A finisher can easily cover such a place by working a film of mortar on the surface without necessarily filling the voids below.

The surface of the pavement should not be finished smooth, but left slightly rough. This may be done by workmen using a wooden float, or it may be done after the work has been floated fairly smooth by slightly marking the surface with a broom. This latter method is perhaps better adapted to rock and sand concrete than gravel concrete, as the latter will leave many small pebbles in the surface and not finish with so smooth a mortar surface as sand and rock concrete.

Expansion Joints.—Concrete pavements have been constructed with expansion joints down the center, across the street and at the curbs; and in some cases no expansion joints have been used. The transverse expansion joints have varied in width from ⅜ in. to 1 in. and have been placed from 25 ft. to 100 ft. apart. The best practice at the present time seems to call for a ⅜-in. to ½-in. expansion joint along each side of the pavement at the curb or gutter, in the case of streets, and ½-in. transverse joints from 25 ft. to 50 ft. apart.

In a paper presented at the recent American Road Congress, Mr. A. N. Johnson, State Engineer, Illinois Highway Commission, recommends that expansion joints be placed at an angle of 60 degrees with the center line of the pavement, and that successive joints be not parallel, but swung first in one direction, and the succeeding joint 60 degrees in the opposite direction, which will tend to reduce any cumulative vibrations. If an expansion joint is at right angles with the direction of the road, then both wheels of a vehicle strike it at the same time and the irregularities become noticeable, whereas, if the joint is placed at an angle, as recommended by Mr. Johnson, the wheels on opposite sides of the vehicle will pass over the unevenness, if there is any, in succession and greatly reduce its effect.

The wearing surface should be cut through at the expansion joints, care being taken to see that these joints extend through the entire thickness of the pavement proper. The sides should be vertical and the edges should be neatly rounded to prevent chipping and spalling.

There are many prepared fillers for expansion joints on the market. The joints should be filled with a suitable elastic water-

proof filler that will not become soft and run out in hot weather, or hard and brittle and chip out in cold weather. A good filler can be made of asphaltum mixed with coal tar and creosote in the proportions of 100 lbs. of asphaltum, 4 gals. of tar and 1 gal. of creosote. These ingredients should be boiled together from one to two hours in a suitable boiler and poured into the joints while hot. Coal tar alone may be used and is frequently used for this purpose.

Sheets of cork, tar and sawdust, tar and cork dust, as well as strips of tarred paper heavily coated with cork, have all been used with success.

In order to protect the edges of expansion joints, they may be faced with steel plates, which are manufactured for this purpose and are cut to fit the crown of the pavement.

Protection.—When completed the pavement should be covered with a layer of sand or straw, and this covering should be kept wet for at least a week, after which it may be taken off, but the street surface should be exposed for about three days longer before being thrown open to traffic. Frequently no covering is put on, and sometimes a covering of burlap is used. Each method has its advocates and each has been used with success. The author prefers a layer of sand, kept well sprinkled for at least five days. (See page 335.)

Under the most favorable conditions for hardening, in hot weather the pavement should be protected from traffic for at least seven days, and in freezing weather several weeks.

The street surface should be wet every day and, if possible, kept fairly wet for two or three weeks after being thrown open to traffic. This requires that there be an ample water supply at hand, and is one feature of concrete construction that in some localities at certain times of the year may prove somewhat awkward.

Contractors should have canvas or other material sufficient to cover about one-half day's work from rain, or, in extremely hot weather, from the sun.

All laborers must be kept off the concrete after it is once in place. Although the footprints can be worked out, dirt from shoes is likely to spoil the proper bond between the materials. By the use of a bridge all need of tracking on the concrete is avoided.

CHAPTER X

INSPECTION OF CONCRETE PRODUCTS

Concrete products or cast concrete work include ornamental shapes, hollow building blocks, lintels, beams, columns, fence posts, railroad ties, sewer pipe, etc., etc. The ornamental shapes, blocks, fence posts, etc., are produced by pouring, tamping or compressing concrete into molds and permitting it to harden to the molded shape.

Inspection.—The casting or molding of concrete products is generally done in regular factories especially designed and equipped for the purpose. In such cases the inspection relates to the finished product alone. Sometimes, however, the casting or molding is done on the work; the inspection in such cases relates to methods of manufacture as well as to the finished product.

The methods of molding and curing are so many that only general directions or instructions for inspection can be given; for special variations in process, the inspector must devise, in addition, rules to fit the particular characteristics of the work in hand. A careful study must be made, for reasons that will suggest themselves, of the surrounding conditions and limitations, and these general instructions modified in accordance.

Art. 54. Ornamental Concrete

Mr. A. A. Houghton's book on "Molding and Curing Ornamental Concrete" has been consulted quite freely in the preparation of this article, especially the last three sections, on molding imitation marble, granite concrete, and concrete to imitate tool-dressed stone.

The construction of ornamental work should preferably be left to those who make a specialty of such work, especially the more intricate ornamental work, being perfectly practicable in most concrete structures having ornament. There is, however, a large amount of simple paneling and molding which the general contractor not only can do but must do. It is essential, therefore, that the inspector or the contractor should have a knowledge of the best methods of doing such work, and also a general knowledge of the special methods of molding intricate ornaments.

Ornaments Molded in Place.—Molding ornaments in place should generally be confined to cornices, belt courses, copings, plain panels, etc. Such work as medallions, scrolls, rosettes, keystones, etc., may be molded in place if desired, by placing plaster molds in the wooden forms at the proper points. This method is often used for keystones in bridge work.

Separately Molded Ornaments.—Bridge railings can be and usually are made up of separately molded posts, balusters, bases and rail. Ornamental columns in building work, brackets, cornices, cornerstones, dentils, finials, flower boxes, keystones, lintels, medallions, moldings, panels, rosettes, spandrels, statuary, windowsills, etc., can be similarly molded and placed in the structure as the monolithic work reaches the proper point.

Methods of Manufacture.—The methods of making concrete ornaments and producing ornamental effects in concrete can be divided into two general classes: (1) *Modeling*, which includes all concrete work built without molds, usually onto wire-mesh frames and modeled into shape by hand or by scraping with templets of wood or metal; (2) *casting* or *molding*, which includes all concrete work made in forms or molds.

Only the second class will be considered here.

GENERAL REQUIREMENTS

All the precautions to be observed in ordinary concrete work are especially important in ornamental work. Modify all blocks or ornaments which you are unable to cast satisfactorily. Check all forms just before molding and keep a record of the blocks cast and see that they are being cast in the order required on the work. Paint the date of casting on each block and keep careful record of them.

Discoloration.—All ornamental work should have a uniform color and should be made of such cements that there will be no efflorescence (see Art. 31). In this connection, see also Art. 39.

Reinforcement.—When pinnacles, base courses, balusters, railings, posts, etc., shall be liable to crack, due to shrinkage stresses and other causes, the same should be properly reinforced to prevent such cracks. Every part of the ornament should have ample strength to support its own weight, no matter how slender or how far it projects beyond the face of the design. Inspectors should report all blocks which in their judgment need additional reinforcement.

Molding Windowsills.—Windowsills with slightly sloping top surfaces should not be molded in place unless absolutely unavoidable. Even with considerable pressure heads results are never certain. The top surface is apt to be filled with air and water bubble holes, impurities in the sand and cement, etc. If molded in place, the surface must be carefully troweled like a sidewalk (see page 484). If cast separately, to be inserted like a stone sill, it should be cast or molded upside down.

Provision for Handling Molded Blocks.—When casting large blocks of concrete which are to be set as blocks of stone, suitable provision should be made for handling by molding dog and clevis or lewis holes in the block, inserting pins or eye-bolts, etc., so that they can be lifted with the derrick. These holes or fastenings should be on the top "bed," being liberal in size and not located too near corners or faces, else the strain of lifting will shell off the concrete. Lewis holes must be so made as not to bring excessive pressure on

the concrete, particularly near the mortar facing or near the arrises of the block. Care should be taken not to handle large blocks with lewises or dogs when they are green. Wood blocks and rag cushions should be provided in turning over the blocks; otherwise the arrises will be broken.

Recesses in Molded Blocks.—The backs of all blocks should have recess places in the back, covering practically one-fourth of the area in the back for the purpose of bonding with the concrete mass. These recesses may be best obtained by placing wooden blocks, say, 4x4-in., 6x6-in. or 8x8-in., in the concrete when first deposited and removing same before final set, the blocks being cast with the most important face down. Beveling the edges of these blocks of wood will facilitate their removal.

Accuracy of Shape and Dimensions.—The block should be true to shape and exact in dimensions, all corners and edges being sharp and well defined, with true horizontal or vertical lines. No block should be accepted that is chipped or marred in any way, but should be equal in perfection to cut stone in all particulars of shape and dimensions. A piece of galvanized iron bent in the shape of a written small "i" should be used where the corners or edges are likely to be stuck. Moldings and other ornaments should be perfect in every detail.

MATERIALS FOR ORNAMENTAL CONCRETE

Every possible precaution should be used in the selection of materials which go into ornamental concrete. While the selection is ordinarily governed by the materials obtainable in the locality, careful consideration must be given to the desired qualities in the finished ornament.

Cement.—The cement for ornamental work must be strong and absolutely sound, otherwise sharp edges will crumble if the cement is not sound. It should meet the requirements stated in Art. 4 for Portland cement, page 43. Cement of the same color only should be used, to prevent streaking.

Where an especially light color is desired, a light colored cement should be used. White Portland cement is eminently fitted for high-class ornamental work. Lafarge cement, a light-colored, non-staining cement made in France, is often used for ornamental purposes. See Art. 42, page 391. White cements are now extensively manufactured in this country.

A light-colored ornament can, however, be secured with any cement by using white sand, marble or other white stone screenings as mentioned on page 391. This method of securing a light-colored ornament is preferred by many, being cheaper and usually superior to the use of white cement. A white or nearly white cement will give the better results where a nearly pure white surface is desired.

Sand.—The sand must be clean and free from loam, or the ornament will have a dirty color, and if any color work is to be attempted, either with pigments or colored stones as mentioned below, cleanness

of sand is absolutely necessary. It should conform in respects to the requirements stated in Art. 8. Sand of the same color only should be used to prevent streaking, unless it is desired to give a varied effect. Facing stone dust or grit and facing sand should all have coarser material removed by screening; $\frac{1}{2}$-in. mesh is small enough for large blocks and large details; use $\frac{3}{8}$-in. mesh for fine work. Be careful, in passing upon the stone dust, that it does not contain a large percentage of rotten rock. All mud balls must be removed for facing work.

Selected Aggregates.—The aggregates must be carefully selected, in order to produce the desired effect, as ordinary concrete is dull and monotonous. This may be done by using for sand and aggregate screenings from stone of the required color, either marble dust and small marble chips to produce a white effect, or selected red, brown or blue stones for color effects (see page 390). This is in all respects the best method of securing colored ornaments, as the color will not fade and the concrete is not weakened. The color and sparkle of the stones must be brought out by surface treatment as explained in Art. 43.

Coloring Matter.—A great variety of pigments are made for coloring concrete. These colors all fade in time, and with few exceptions they all weaken the concrete. For methods of using coloring matter, see page 394.

PROPORTIONING AND MIXING CONCRETE

The mixtures used in ornamental work will depend upon the detail of the ornament and upon whether color is or is not required.

Mortar Finish.—Generally a rich mixture of cement and sand or fine stone screenings is used for the surface and backed with an ordinary concrete mixture (see Art. 41, page 385). A surface mixture of fine material will be required where clear, sharp lines and edges or corners are demanded.

Consistency of Mixture.—The chief requisite to insure success is a mixture that will penetrate and fill all the lines of the mold, as well as produce an even texture or grain to the cast. For methods of mixing concrete, see Art. 15.

MOLDS USED FOR ORNAMENTAL CONCRETE

Molds for concrete newels, finials, rails, balusters, spindles, balls, caps and bases for piers, etc., should be so constructed as to be easily operated with perfect results without the use of unusual skill. They should be so constructed as to be removable piece by piece without injuring the casting, and should follow out the absolute perfection of architectural lines and artistic appearance. Molds should have ample strength and rigidity to withstand tamping and other strains without distortion.

All blocks should be molded in forms which are level—that is, which rest on a level platform—and great care should be taken by the inspector to see that the forms are stiff and do not bulge or distort

under the concrete. If this is not done, the contractor will find it necessary to do a great amount of cutting, which in many cases will result in going through the mortar facing in order to get the block out of wind.

The molds used for ornamental concrete may be made of wood, iron, sheet metal, sand, plaster of Paris, glue, etc.

Dividing the Molds.—The molds must be properly divided so that they will draw along the line of the least resistance or friction. At no point must any section bind or cling to a projecting part of the cast, otherwise a broken cast may result. The sections should part from the concrete surface without the least friction or adhesion, and must be planned so that this is assured, relying upon supporting forms to retain the various sections in the proper position when the mold is assembled. All molds made in sections should be carefully fitted and should be equipped with locking and squaring devices which will accurately bring all sections into perfect alignment.

Wooden Molds.—Wooden molds are considered the best for general work where plain shapes and not too delicate ornaments are wanted. The use of the various stock moldings permits a great variety of designs to be made up in wooden molds, being so joined as to draw easily from the concrete cast. The joints of a wood mold must be accurate and properly held with a clamp or any other method that will hold same rigidly yet permit the sections to be taken from the cast without shock or vibration, as would be the case if they were nailed.

Wooden molds give the best results with a dry and rather coarse-grained surface mixture. If a wet mixture is used, such water as flushes to the surface cannot escape, and small pits and holes are formed, which necessitates grout or other finishing.

The construction of forms for ornamental work in place must be carefully watched so that the forms can be removed without fracturing the ornament. Proper provision for the swelling of the forms is another point to be watched (see page 209).

Iron Molds.—The same disadvantage in the use of wet mixtures applies to iron molds as to wooden ones, stated above. Iron molds, however, can be made to mold more intricate ornaments and are far superior to wood for durability. They can be ordered cast to pattern in almost any foundry.

Sheet Metal Molds.—Stamped sheet metal has been used to some extent as a molding material, being cut and applied to the face of the mold. The sheet metal forms a mold on the back or reverse, which is stamped deep enough to hold the concrete perfectly, thus reproducing some excellent designs in ornamental concrete work by this method. See also Art. 17, page 203.

Sand Molds.—The sand mold process has produced the most satisfactory ornamental concrete work of any process so far employed, the surface, texture and detail of the ornament being especially fine. An advantage of this system of molding is that the work so cast does not as a general rule craze or develop checks, cracks, or map-crazing—an advantage of some importance in molding

ornamental concrete work that must depend largely upon surface finish for its appearance. Sand molding is, however, a more expensive process than molding in wooden or iron molds, on account of a separate mold being required for each ornament molded.

Molding concrete ornaments in sand is in all respects like molding castings in a foundry, requiring merely a wooden pattern and iron-molders' sand. A high degree of skill is not essential to perfect work. The wet sand is tamped into a retaining form around the pattern, leaving an imprint of a portion of the pattern in each part of the sand mold; these are assembled and the work cast in the usual manner employed for ornamental concrete as described below. The wet sand forms a coating or blanket around the cast, retarding the drying-out process and thus increasing the strength of the concrete, without attention during the curing process.

Plaster Molds.—Plaster molds are made from clay, gelatin or other patterns in a manner similar to that adopted by sculptors. The usual grade of plaster employed is plaster of Paris, either in the usual state or mixed with any ingredient that will retard the set or hardening of same. Wood fiber plaster or wall plaster is sometimes used as a material for molds and gives good results. Plaster molds are particularly adapted to fine-line and under-cut ornaments.

The placing of the plaster depends upon the shape of the pattern. Plaster molds must have a waterproof coating, owing to their porosity. This coating may be shellac, glue or oil paint, the mold being oiled each time before making the cast.

The concrete is poured into the plaster mold, and after the cement has become hard the plaster is broken or chiseled away, leaving the cast exposed.

Glue Molds.—Glue molds have been extensively used in the finer lines of ornamental concrete work, its elasticity permitting removal from work having a considerable undercut. While glue molds produce excellent work, they are not durable and require considerable care to make in order to have perfect.

The model is first placed upon the molding bed or board and well oiled, a coating of modeling clay being then placed over same to the thickness desired for the glue mold. Over the clay coating is built a plaster shell, which is removed as soon as it has hardened, and the modeling clay taken from the model or pattern. Melted glue is now poured into the space left between the plaster shell and the model, the plaster shell being pierced at the highest point for inserting a funnel for pouring the glue, and at several other places, to permit the steam from the hot glue to escape.

Care should be taken to have the model or pattern well oiled before pouring the glue, and also to have the plaster shell properly placed and securely fastened at the edges so that it cannot slip. The melted glue should be poured slowly into the opening at the top of the plaster shell, thus allowing giving the glue a chance to run to every portion of the mold, also keeping the vent holes open with a piece of wire. After the glue has been allowed to cool or harden, the plaster shell and glue mold can be removed from the model. The

glue mold is now cut into sections, if this is necessary. Usually the glue mold will draw from the concrete cast without many sectional joints.

The glue mold should have an oil coating before each cast is made in same.

A well-molded glue negative may be used about fifteen times.

COATING THE MOLDS TO PREVENT STICKING

The coating of the molds for ornamental concrete must insure their parting from the cast without adhering in the least, otherwise small particles will be broken or scale from the surface, requiring much labor to repair. This coating must be of some material that will form a non-adhesive film over the face of the mold, thus insuring clean partings between mold and cast.

Use of Shellac and Oil.—Plastic molds, such as plaster, plaster compositions, etc., may be coated with shellac, to give them a smooth and moisture-proof surface, after which they should be coated with oil having a thick body. Crude petroleum and also heavy machine oil may be used for this purpose. The choice of other non-adhesive films has run from vaseline to hog's lard. An oil coating, if without mineral coloring matter, does not injure the surface of the work, and is absorbed into the pores of the cast in drying or hardening. This oil coating may be removed from the surface when the cast is subjected to any of the surface treatments described in Art. 43.

Use of Shellac and Paraffine.—Where the mold is made up of small sections a better method than the one described above is to coat the surface of each plaster section with shellac, and when this is dry each section is quickly dropped into melted paraffine wax (see page 442). The film of paraffine thus formed over each section of the mold is absolutely non-absorbent, making it positive that the concrete cannot stick to the mold. Paraffine should be applied after each casting, in order to insure that the sections of the mold will draw perfectly.

Use of Oil with Wooden Molds.—Wooden molds demand a treatment that will fill the pores with a moisture-proof compound, so that the wood will not absorb the moisture from the concrete and thus cause the concrete to adhere to same. Usually an oil is the best for this purpose (see Art. 18, page 241). A compound of linseed oil and petroleum, mixed one-third petroleum to the volume of oil, may be painted over the surface of the wood and allowed to penetrate until the wood takes up all of the compound that it will. Undiluted linseed oil, oil paint, and various compounds of a similar nature may be employed for this purpose.

The molds must be thoroughly dry before applying the oil coating, otherwise the wood will not absorb enough oil to do any good. Three or four coatings are usually necessary, depending upon the kind of wood and also the condition of same at the time of treatment. Molds should be thoroughly coated with oil after each casting.

Use of Enamel.—Molds may be coated with a bath-tub enamel or

any enamel coating that is proof against moisture. The enamel should be laid with a soft brush and not allowed to run, otherwise it will not produce a smooth and even surface coating. The smooth and glossy surface produced on the cast is similar to that produced by molding over sheets of glass as a molding surface. Metal molds may be prevented from sticking by baking the enamel on so as to produce a durable coating.

Use of Powdered Chalk.—Molds may be coated with powdered chalk, mixed to the consistency of thick cream and applied with a brush. This coating will be found very useful for metal molds or upon any surface that is smooth. The chalk is not injurious to the concrete and can be easily removed by washing the cast with water. A chalk coating tends to lighten the surface of the concrete, but is not permanent.

Use of Fine Sand.—Where the face of the work is down, the mold may be prevented from sticking by sifting onto the face plate or bottom of mold a dry mixture of fine sand and cement to a depth of about an eighth of an inch. The wet mortar or concrete is placed upon the top of this dry mixture and tamped or puddled, the dry material taking up the surplus moisture upon the face of the cast. The work will not stick any more than damp sand would adhere to the mold, and the dry material bonds with the wet mortar or concrete placed upon same, and thus becomes a part of the cast.

The molds may also be oiled with gloss oil and fine sand then thrown against the oiled surface with a bellows.

Use of Soap.—Cheap soap boiled and applied hot to wooden molds gives very good results in preventing the adhesion of concrete to molds. In this connection, see Art. 18, page 242.

Use of Paper.—The use of paper needs constant attention in order to secure satisfactory results. Unless the paper is very oily it will adhere to the concrete, necessitating that it be burned off so as to effect its removal, as a thorough soaking very seldom removes the paper entirely. The practice of using wet newspapers is not to be commended, as it is almost impossible to keep the paper absolutely smooth so that the final surface does not show wrinkles, thus making a serious defect in the cast. (See page 243.)

PLACING THE CONCRETE

The success or failure of the cast depends largely upon the manner of placing the concrete into the mold, for if the work is carelessly placed, air bubbles or holes will result. Care must be taken to press all the lines and indentations of the mold full of the mixture and at the same time force the entrapped air to the surface so that the place it occupied may be taken by the concrete.

Cast all blocks with most important face down. All other showing faces should be cast vertical, or as near vertical as practicable. The back of the block—that is, that portion of the block which will not show in the structure—should always be molded up, because the laitance or slime always rises to the surface, giving it not only a bad color, but a weak surface, and one which is certain to hair-crack.

Puddling.—The density of the mass must be secured by puddling (see Art. 25, page 296), because pressure is not possible with any mold as easily broken as a plaster, glue or wooden mold. This is done by stirring the concrete with a paddle or stick long enough so that it will reach to the bottom of mold, and small enough to enter the gate or opening for pouring in the concrete. There should be several different sizes and lengths of paddles or sticks made, so that the best one for the purpose is already ready. The paddle or stick should be worked or forced into all the minute lines of the mold, and at the same time bringing the surplus water and the air confined by the concrete to the surface.

Care must be taken not to have too wet a mixture, for a surplus in excess of what the concrete will hold will be pressed to the surface between the concrete and mold and there form minute holes when the water has evaporated upon the concrete drying out. The concrete should be poured in small portions, say, from one-fourth to one-eighth of the mold at a time, thus permitting the concrete to be well puddled and at the same time giving one an opportunity to judge the condition of the concrete, i. e., whether too wet or too dry. Any excess of water that rises to the surface may be removed by using a swab which acts as a mop, taking up the surplus moisture from the concrete at any point in the mold. The pouring should be close enough together so that the concrete will bond perfectly without showing layers or laminations; usually from three to five minutes apart is ample time to thoroughly puddle the concrete between pourings.

Precautions.—Care must be taken that the concrete is mixed in exactly the same proportions, preferably by weight (see page 150), for each batch poured; also that no dirt or foreign material falls into the mold between pourings; otherwise the work will be in layers of varying degrees of color.

Do not cast blocks in freezing weather (particularly thin ones) without taking extraordinary precautions to protect the concrete from the cold. (See Art. 33, page 349.)

REMOVING THE MOLDS

Considerable judgment must be exercised as to the best time to remove the molds, so that the concrete is the most susceptible to surface treatment, when the molds are removed. Under usual conditions the concrete is at the best when 24 hours old and usually when the work has remained in the molds over 36 hours, it is not as easily treated to obtain a perfect surface finish and color (see Art. 43).

Time of Removing Molds.—The time that must elapse after the concrete is poured and the molds are removed must vary with the size of the cast, the mixture, and also the atmospheric conditions at the time of molding (see Art. 19, page 245).

A cast of large body will contain more weight, and if this is supported on a slender pedestal the concrete must attain more

strength before the molds can be removed than if the weight is slight and amply supported. The molds should never be removed until the cast has set and hardened to such strength that it will sustain its own dead weight.

When mixed wet, concrete sets and attains its strength more slowly than when mixed with very little water. In other words, wet concretes require longer to harden than dry concretes.

The condition of the atmosphere will also affect the work, as the work will harden faster upon a hot, dry day than upon days when the air is heavily laden with moisture.

Care in Removing Molds.—In removing molds, care must be taken that the sections part from the cast under gentle pressure. Any jar or vibration necessary to the removal of the mold may produce a serious defect by scaling off of a projection on the cast.

Cleaning Molds.—The molds should be thoroughly washed out on the molding surface, when removed, so that they will be in readiness for the next cast. If any portion of the concrete should adhere to the molds it can now be removed easily, where in a few hours it would be almost impossible to remove same without injuring the mold (see Art. 18, page 237).

REPAIRING DEFECTS IN THE CAST

All cast work, as soon as extracted from the molds, should be examined for defects, air-bubbles, etc., and any blubs stopped and chipped parts or other minor defects made good while the work is moist or green, using a small trowel and mortar mixed in the exact proportions as employed for the main body of cast. The repairing of defects requires skill to secure a plastic mortar that will match the surface texture and color of the cast (see Art. 30).

Where the work can be laid down so that the defect is uppermost the hole can be filled with the mortar, or neat cement and colors in the same proportion as used for the surface stuff, and allowed to harden before removing the cast.

Bonding Mortar to Cast.—The new mortar may be bonded to the cast by using a stiff bristle brush of small size, wetting in water and thoroughly brushing the spot to be repaired, so as to remove the thin film of cement that covers the aggregate. If this has not permanently hardened, the simple brushing with water will usually expose the particles of aggregate, to which the new mortar will easily bond. For other methods of exposing the aggregate, for the purpose of bonding, see Art. 27.

Colored Work.—Colored surfaces may be improved by brushing the cast as soon as set with a solution of the same color as used for the surface coat. See also Art. 44, page 408.

SURFACE TREATMENT OF CONCRETE

The surface treatment should be given attention as soon as possible after the molds have been removed, for the concrete will harden rapidly in a few hours after the molds are drawn.

There are several advantages to be gained in treating the surface of the concrete after molding, first, the danger of crazing or map cracking is reduced to the minimum; second, the work has a more uniform color and surface finish; third, any little imperfections in the molding may be covered up or removed.

The surface treatment demands patience and care to insure that a smooth, even texture and color will result.

Scrubbed or Brushed Finish.—Aggregates composed of marble, crushed granite or various colors of silica sand, may be exposed by scrubbing with a stiff bristle or scrubbing-brush and water, which removes the thin film of cement that covers the particles. This scrubbing should be done within 12 to 24 hours after molding. If the molds have remained upon the work for several hours too long, or if the surface has hardened too much for the bristle brush to take effect, a wire brush may be substituted, keeping the surface thoroughly flushed with water, so that all particles will be washed away as fast as removed. In this connection, see Art. 43, page 397.

Rubbed Finish.—The surface of the concrete may also be allowed to permanently harden or cure and then be brought to a uniform color by rubbing with sand-paper or emery-paper. This process is usually limited to small ornaments, as the work is very tedious.

A carborundum stone, cement block, brick, etc., may be substituted for the sand-paper or emery-paper mentioned above. The surface of the hardened concrete should be thoroughly wet and then rubbed with the carborundum stone, etc., until a lather is produced. The surface should then be flushed with water and dusted with dry sand and cement, mixed in equal proportions. This should again be rubbed with the coarse stone and the surface cleaned with a brush wet in water. The final finish may be secured by rubbing with a fine grained brick or carborundum stone. This fills the pores of the concrete and makes it smooth and lighter in color, as well as moisture proof. In this connection, see Art. 43, page 400.

Where the surface may be exposed within 10 to 16 hours after molding the work can be rubbed with burlap, to produce a rough grained finish that will answer to many purposes.

Acid Wash Finish.—Applying dilute muriatic acid (commercial) to the surface consists of another type of the scrubbing or brushing process described above, the acid removing the film of cement coating over the aggregate and exposing same to view. For a cast which is about two weeks old, ordinary commercial acid may be diluted with three parts of water. When but a few days old a dilution of one part acid to five or six parts of water should be used. The amount of dilution should be determined by experiment as it varies with the age of the concrete. The solution should be flushed with water to remove all traces of the acid, after being brushed upon the surface. See also Art. 43, page 401.

The soaking of concrete surfaces in acid will not only result in a great saving of acid, but will produce a class of work that cannot be obtained with the scrubbing brush. A very weak solution is required (depending upon the age of the concrete), and after the

article is put in the tank, the solution does the rest. This treatment preserves the edges and details of the design and makes the surface uniform. Any of the hard spots not sufficiently affected by the acid can be treated separately after the article has been flushed with clear water.

Care must be taken that aggregates of the surface are of nearly uniform hardness, or the acid will eat the soft portions out before the harder particles have been cleansed of the cement coating. Very fine work has been spoiled in the attempt to obtain certain effects where black marble (a limestone) was mixed with crushed granite. The acid bath in such cases left only the spaces where the black marble had been, while the granite showed a very fine texture and natural color.

Tooling and Sand Blasting.—The treatment of the surface by tooling or by sand blasting is not as successful for ornamental concrete as for work with a large expanse of surface (see Art. 43, pages 403 and 405), for the fact that it cannot be accurately controlled enough to permit working along minute lines, as would be necessary in the average ornamental cast.

Concrete should not be dressed (tooled) until 30 days old, under normal conditions, preferably not under 60 days. One-quarter to 3/8-in. should be allowed beyond all neat lines for dressing. All arrises should be chiseled. Better work can be gotten by using hand hammers than machine ones, and concrete details subject to close inspection by the public should be hammered by hand. All arrises excepting those of abutting joints should be rounded to approximately a 3/8-in. radius. If this is not done, the public will eventually knock off the fine arrises. Use metal templates for cutting important details.

Coating Surfaces.—The work may also be coated with any of the concrete finishes described in Art. 44. The use of any concrete coating or paint-like substance, over the cast, has a serious handicap in the fact that it usually does not prevent crazing, checking or map cracking. In fact, too thick a brush coat of any of the concrete finishes now on the market, or of cement and water, etc., will increase the tendency of the surface to craze. While a finish may be used after the work is thoroughly cured, such as to cover the cracks or other defects, yet if this should be removed by any cause, the unsightly defect would be increased.

A brush coat may be made by using one-third the weight of the cement in hydrated lime, mixing the compound to the consistency of paint, with water, and applying to the surface of the cast with a brush. This coat will render the concrete more waterproof than it was originally by filling its pores.

A color solution, made by mixing the color with water and a solution of alum, may be brushed over the surface while it is moist or green.

Coloring by Immersion.—The absorptive qualities of concrete during its stage of curing and seasoning offer opportunities for coloring concrete products by capillary action. By this method, the color is

deposited into the pores of the surface, amalgamating with the concrete in a permanent unit.

Coloring solution can be made to penetrate the surface of concrete six inches or more, if the object is placed in the solution in a very green state. It is seldom necessary to penetrate more than 1/16 in. to 3/16 in.; this thoroughly fills all pores, gives the desired color effects, and is less expensive.

Aniline color and the sulphates of copper and iron are the most suitable to make solutions in which to color concrete products by capillary method.

The concrete to be colored can be treated after it is several days old. Concrete products with strength requirement should not be subjected to the coloring bath until the concrete has attained its required strength, as the filling of the pores in the concrete stops the action of its curing by the usual methods.

Coloring by absorption is effective on surfaces of concrete after it comes out of the mold, or after being treated with acid (see page 514) or tools (page 515). Surfaces that have been colored by absorbing mineral or metallic colors (see page 391) become waterproof, and the action of the weather on the metallic colors is the same as on real metals, increasing the beauty of coloring by the usual oxidation noticed on bronze and copper. Surfaces of concrete treated by this method become so hard and dense that they will take a uniform dull or high gloss polish (see page 514). Such surfaces may be treated in the same manner as marble, granite and metal, under polishing or buffing machines.

Waterproof paints containing coloring matter are to be recommended for dry or semi-dry process concrete work, as the porous surface readily absorbs the waterproof liquid, and allows the pigment particles to fill the pores. While the color effect obtained in this manner is the most economical, yet it is a flat color, and does not give the richness and depth of shading that results from the immersion treatment in an aniline or metallic bath. It has the advantage, however, of being used in cases in which immersion is not practicable.

Excellent two- and three-color effects have been obtained by painting certain parts of ornamental casts before subjecting them to the coloring bath. The parts so colored are not usually affected by the color in the bath. The artistic possibilities of such treatment are limited only by the color sense and taste employed by the craftsman. By using certain non-absorptive aggregates (see page 390), their natural color can be obtained, while the absorptive parts will assume the desired color. In this treatment, precaution must be taken not to use certain acids in washing before immersion in the color bath, as the chemical action of the acids is likely to counteract the color value of the bath.

CURING THE WORK

Upon the proper curing of the cast depends to a considerable extent the success or failure of the ornamental work attempted. With

little or no attention to the curing of the product, the most promising cast will develop unsightly defects, such as crazing, checking, discolorations, etc. The intelligent care used in curing the cast has almost as much to do with attaining its ultimate strength as the quantity of cement used.

As a general proposition, immersing ornamental concrete work in water does not cure the work so satisfactorily as does the sprinkling process, or the application of exhaust steam for forty-eight hours.

Keeping the Cast Moist.—After the cast is safely set it should be gently sprayed with water or kept moistened with wet blankets, care being taken not to have the spray of such force as to disintegrate the face of the cast or mar the corners. After the work has had time to harden, say from twelve to eighteen hours, the addition of water directly upon the surface has no effect, provided it is gently sprayed. Even after thirty-six hours from the molding, and the molds just removed, the effect of a constant streak of water directed at one point has caused an injury to the surface. (See page 335.)

Instead of spraying the water on the cast as just mentioned, the work may be surrounded with a framework of lumber, just a few inches larger than the cast, and covered with wet blankets. These blankets should be kept wet for the first few days, usually from three to six days, depending upon the condition of the atmosphere at the time, the six-day limit being used for hot, dry atmospheric conditions. If the air is damp, as would be the case in rainy weather, the blankets and form can be removed at the third day. Care must be taken to keep these blankets thoroughly saturated with water.

Blocks which have sharp corners or arrises or any sharp projections must be given special care to keep these projections moist and prevent their drying too rapidly. This precaution is of far-reaching importance, and failure to provide the necessary amount of moist will cause the corners to crumble at a touch, owing to the corners drying out before the initial set is fully completed.

Steam Curing.—The curing of ornamental concrete by steam confined in a close room or under blankets or tarpaulins placed over the work has been successfully employed by many plants. The usual manner of placing the steam is through a pipe perforated with a number of small holes, and this placed so that the concrete will be enveloped in the steam jets issuing from these holes. The usual time of steam curing is about forty-eight hours in the kiln and then removal to the open air.

Care must be taken that the cast is so stored during the steaming process that it does not collect discoloring matter from chimneys or other sources. Soot from chimneys is very apt to discolor the work, at least until the concrete has permanently hardened.

Care in Handling.—Care must be used in handling green casts or cracked casts will result. Carelessness in handling green casts frequently results in the formation of fine cracks, which, though unnoticed at the time, give evidence of their presence later in the failure of the casts.

MOLDING IMITATION MARBLE

The most successful aggregate to produce imitation marble is marble flour or dust and white sand; this is mixed in the proportions of 1 part of marble dust to 2 parts of the sand, to which is added 1 part of white Portland cement; this makes a 1:3 mixture.

Use of Glass Slabs.—Where flat slabs are desired the mold should be lined with plates or sheets of glass; upon this a thin coating of the concrete is laid to a thickness of about 1/4 in., being floated or troweled, so as to bring all the confined air and surplus water to the top of the troweled surface. The balance of the concrete is then added, which bonds with the thin coating placed upon the glass surface and makes a perfect slab, without the usual air-bubbles or minute holes in the surface. Many pieces of work have been produced in this manner with a smooth, glossy surface, capable of reflecting light, fully the equal of polished marble.

Use of Molds Coated with Enamel.—Bath-tub enamel may be substituted for the glass slabs mentioned above for lining molds. Such an enamel coating will produce nearly the same effect as the glass slabs, making it possible to mold concrete that will reflect light like polished stone, with lines and relief design of the most intricate pattern.

Surface Treatment.—The effect of polished marble is increased if the cast is allowed to harden for about a week and then rubbed or polished with a piece of felt, dampened with oxalic acid. This produces upon the concrete the luster of polished stone, and if this is repeated whenever it is desired to clean the concrete surface, the effect can be made lasting. The marble aggregate may also be exposed by treating the surface as described in Art. 43, although this will injure the smooth, glossy surface.

Imitation Marble for Ordinary Concrete.—Where a marble finish is demanded to a large body of ordinary concrete, the surface of the forms may be coated with dry marble flour and white Portland cement mixed equal parts. This is sifted in dry to a thickness of about an eighth of an inch, and the wet concrete body placed upon same. A mixture of white cement, marble flour and white sand also makes an excellent facing mixture for this purpose and insures a lasting and successful finish when so employed. It may be mixed in the proportions stated above.

Imitating the Vein in Marble.—The vein or color in marble is easily secured by employing a thread or string saturated in a thin solution of aniline color or any permanent dye; this is placed upon the concrete surface, following the line selected for the color to run. The effect is increased by placing the thread in irregular or zigzag lines upon the surface of the work. The concrete absorbs the color from the thread or string by capillary attraction, thus causing it to permeate the surface of the concrete for several inches on each side of the dye saturated string. This causes the color to be the deepest at the point the string lies upon the surface, and from that point it blends outward in gradually diffusing shades, until it is lost in the

white surface of the concrete. Care must be taken to have the string well saturated with the dye, otherwise the work may appear too streaky, being too much unlike natural marble.

Another method is to apply the color or dye with a fine brush, penciling the lines in the same manner as employed in laying the thread or string. The color is absorbed by the concrete and the capillary action distributes same over a portion of the surface upon each side of the penciled line.

MOLDING GRANITE CONCRETE

Crushed granite or quartziferous sand, well graded, should be used. This can be purchased of a number of dealers and usually is in the right proportion of light and dark colored grains to give excellent results. White Portland cement should be used in preference to ordinary cement. The use of white Portland cement gives a lighter color to the surface in imitation of the light gray granite. Ordinary Portland cement, on the other hand, gives a darker shade, which can be increased by adding a little lampblack (see page 396) to the cement; this is desirable if an imitation of a dark gray granite is to be secured.

Selected Aggregate.—The addition of yellow, pink or red silica sand to the crushed granite will produce varying lines that are of great value (see Art. 42, page 390). True granite is composed of quartz and potash feldspar; the usual or natural color is a shade of gray, but, when accessory minerals are present, the stone may be of various shades of green, yellow or pink, and even a deep red. Colored silica sand or even mineral colors may thus be employed in almost any color scheme without departing from the hues of granite as it appears in a natural state.

Proportions.—If the aggregate is well graded a proportion of 1:3 will give very successful results, but if the sand or granite is composed of very fine grains, more cement is demanded and a mixture of 1:2 may be required. The particles of crushed granite are generally very hard, sharp and usually clean, with a minimum of fine dust. This permits a 1:3 mixture with greater strength than the use of crushed marble in the same proportions. Marble is merely limestone that is crystalline, which is easily crushed in comparison to granite, thus causing a large percentage of fine dust or flour to be present in the product. This requires a greater percentage of cement than where the particles run from coarse to fine.

Molding Granite Concrete.—Granite concrete may be molded in a manner similar to that described in Art. 41 for ordinary concrete work.

MOLDING CONCRETE TO IMITATE TOOL-DRESSED STONE

An imitation of tool-dressed stone may be secured by coating the surface of the mold with a thin wash or size of glue or shellac, and while this is yet tacky, sifting coarse sand over the surface. This is held by adhesion and dries in that manner, making the surface

of the mold like ordinary sand-paper. This is then given a coating of shellac, and then oiled, to prevent the concrete from adhering to same, or bonding to the sand, as it would if it were not treated. The sand surface molds the concrete with a vast number of minute indentations and points upon its surface, in close imitation to tool-dressed stone.

Rock-Face Finish.—A rock face can also be secured in the same manner. The face of the mold is given a heavy glue coat, and in this is embedded spalls or pieces of broken stone or gravel, arranged in the form that it is desired to have the indentations in the concrete. This should be well treated with shellac and oil. This molds a reverse of the rock surface in the concrete. For other methods of securing a rock-face finish, see Art. 43, page 400.

Art. 55. Concrete Building Blocks

The use of concrete building blocks as a substitute for wood, brick, and stone has become very extensive within the past ten years. Concrete blocks, when properly made and used, form an excellent material for building construction. They are made with rock face, smooth face, or ornamental face, as desired. The walls of the building are made of hollow blocks, with continuous air chambers, or of blocks which, though not themselves hollow, can be laid so as to produce a hollow wall.

The forms and sizes of blocks are endless in their variety. They are used for straight walls, pilasters, corners, bay windows, chimneys, chimney breasts, window and door caps, sills and sides, string courses, water tables, cornices, etc.

MATERIALS FOR CONCRETE BLOCKS

Concrete building blocks are constructed of cement, sand, gravel, or broken stone and water mixed in proper proportions. Sometimes the gravel or broken stone is omitted, in which case the blocks are properly called "mortar" or "cement" blocks, although the term concrete is still applied by a few block makers.

The fundamental principles governing concrete block construction, so far as relates to the qualities of the materials, does not differ materially from that of ordinary concrete construction, and has been fully discussed in Chapters I and II of this work. In other words, the materials for block construction may be selected according to the same principles as are applied in making ordinary concrete.

Cement.—Natural and Puzzolan or slag cements are sometimes used for making concrete blocks, and, while greatly inferior to Portland cement, may be used for work which will be constantly wet, but should be avoided for work exposed to dry air, as such blocks fail from cracking and shrinking (at the surface only) in dry air. No cement is as fully reliable as Portland cement, and the highest grade of the latter should be considered for concrete blocks.

The selection of a proper cement for use in concrete block manufacture is of the utmost importance. Only a so-called "sound" cement can be used in the manufacture of concrete blocks which are made to resist the action of time, water, and atmospheric gases. An excess of "freelime" will in time become hydrated, and swell, exerting such great force as to disintegrate what may have been blocks which have proved hard for a long period. Certain brands of cement are much more liable to this tendency than others.

Color is another point to be considered in selecting a cement for making concrete blocks, as the various brands dry out in different colors, some being light and some dark in shade,

A white Portland cement is often used in facing blocks because of its lighter color and its waterproofing quality (see Art. 42, page 391).

The cement should be tested or warranted by the manufacturer and must be a high-grade, slow-setting Portland cement.

Several substances having claims to strengthen or accelerate the action of Portland cement are now on the market, but they must be used with great caution, for even if they do appear to strengthen the cement when first made they may have a deteriorating action similar to some of the waterproofing compounds on the market.

Hydrated Lime.—Lime is sometimes mixed with cement mortar, being used to replace a portion of the cement and to improve the qualities of the mortar for block making. The dry-slaked or hydrated lime is the most convenient form to use, and is now a common commercial article (see Art. 48, page 428).

Hydrated lime is mixed in the proportion of one-quarter to one-half of the cement employed. A mixture of 1 part of hydrated lime to 4 parts of cement will be safe, and in some cases beneficial. The addition of hydrated lime is of less benefit to a mixture that is rich in cement and so proportioned as to fine and coarse aggregate that voids are reduced to the minimum than to a mixture that is poorly graded. Before employing it, a little experimenting should be done by securing a few pounds and noting the difference resulting from its use in the mixture.

The addition of hydrated lime in the proportions stated above will cause the blocks to set more rapidly, will make them lighter in color, and the concrete will be denser and more impervious to moisture. In other words, the use of hydrated lime generally secures greater density and impermeability in the block, besides lighter color.

In sand mixtures with the proportion of 1:4 or 1:5, at least one-third of the cement can be replaced with hydrated lime without appreciable loss of strength.

While hydrate of lime is the most convenient material for making concrete blocks impermeable by filling the voids, its cost is practically as high as that of cement, and carefully slaked lump lime is more often employed.

Sand.—The sand should be clean and free from clay or loam when used for the face or exposed part of the block. For this reason, river sand is usually preferable to pit or bank sand, although bank sand

is sometimes free from foreign matter. A small proportion of clay may be allowed in the sand for the body or that part of the block which is not exposed, which in many cases makes the blocks of a wet mixture stand up better than when perfectly clean sand is used, and does not decrease their strength. Too much clay, however, is injurious (see page 91).

Sand should preferably be round and, except for the face of the block, should be fairly coarse; or, better, should range from fine to coarse for the body of the block.

If the sand for the face is not perfectly clean, it should be washed before using (see page 103); that for the body may contain a small proportion of clay without detriment to the strength of the block, usually about 5 per cent.

The sand should be screened, if necessary.

The sand should be tested as to fire-resisting quality, when blocks are liable to be subjected to fire (see page 119).

Artificial Sand.—The following materials can be used in place of natural sand in making concrete blocks: (1) Stone screenings and (2) Crushed oyster shells.

Stone screenings, if they do not contain too much fine dust, will give as strong a block as can be made from natural sand. Screenings or crusher dust from soft stone should not be used, as blocks made from them will be weak and undesirable. (See page 85.)

In the Southern States, where no sand is obtainable, crushed oyster shells may be used. These furnish a good, clean, and sharp material, whose only objection is that blocks made from them do not resist fire very well.

Gravel.—A hard, clean gravel should be used in making concrete blocks (see Art. 9). The gravel should be irregular in size, varying from fine to coarse. If it contains over 5 per cent of clay, the gravel should be washed. The gravel will usually be mixed with sand and, provided there is very little foreign matter in the natural mixture, it may be used without screening by adding the required amount of sand or gravel, as the case may be, to secure desired relative proportions between fine and coarse aggregate.

Broken Stone.—Broken stone affords a good material for making concrete blocks, trap rock and granite being the best materials for such purpose. While limestone makes a good aggregate for concrete blocks, its chief objection for such work is its liability to disintegrate in case of fire, because when the blocks are heated the limestone is calcined to quicklime, and the blocks collapse, particularly if water is thrown on them. Otherwise, limestone is very desirable. The softer sandstones should not be used, because a concrete cannot, in the nature of things, exceed the strength of its aggregate.

If much dust is present in broken stone it must be removed by means of a small mesh screen. Another way is to wash out the dust (see Art. 10).

Cinders.—Concrete blocks made from cinders are inferior in strength to those made with gravel or broken stone, because the cinders are easily crushed and are very porous. For these reasons

they should not be used in situations where great strength is required. They will prove the most satisfactory for interior walls carrying light loads.

Cinders must be used cautiously, as they often contain dangerous impurities and particles of unburned coal (see Art. 11). They should be free from ashes and sulphides, being carefully washed, screened of ashes, and the coarse particles crushed.

Size of Aggregate.—In making building blocks it is always an advantage to use as large a size of broken stone or gravel as can be conveniently worked in the mold, but the spaces to be filled are usually too narrow to permit the use of very coarse materials, thus limiting the block maker to the use of aggregate not exceeding ¾ in. in size. Aggregate larger than 1 in. in size can very seldom be used, and, as a rule, sizes ranging from up to ½ or ¾ in. are the maximum sizes that will prove satisfactory.

If the gravel runs over ¾ in. in diameter, it will generally be necessary to screen out the larger sizes, but ¾-in. sizes can be used in most block molds.

Where possible, graded sizes should be used, and for the best results at least one-third of the material should be coarser than ¼ in. A 1:5 mixture containing such gravel or broken stone will be found as strong and as durable as a 1:3 mixture of sand alone.

Water.—The water used in making concrete blocks must be clean and especially free from injurious minerals and animal or vegetable matter (see Art. 12). Many blocks have been spoiled by using dirty, impure, muddy water.

Use of Salt.—Sodium chloride or common salt is often added to concrete block mixtures in freezing weather, 10 per cent of the weight of the mixing water being generally considered harmless (see Art. 33, page 351). There are, however, other methods of satisfactorily overcoming the difficulties attendant upon winter work as described in Art. 33.

Coloring Matter.—If blocks of a particular color are to be produced, it is necessary to color only the face of the block as mentioned on page 391. The more correct way to accomplish this is by the use of selected aggregate, such as colored sands or pebbles, as described in Art. 42, page 390. This, however, is sometimes impracticable, and in such cases resort must be made to mineral coloring matter as described in Art. 42, page 394. There is one coloring matter that is a benefit—that is lampblack; all other colors are more liable to be an injury than a benefit.

Waterproofing.—There are several methods or preparations used for waterproofing the blocks, special mixtures being used in the concrete, in a special facing mixture or applied to the surface of the blocks, as described in Arts. 48 and 49. One very important adjunct to all these methods of keeping water out of a wall is the density of the block itself.

Various proprietary compounds are on the market for waterproofing concrete blocks, some of which are mixed with the cement in the same manner as hydrated lime (see page 433). The merits of these

compounds can be judged only by results, as they are usually made by a secret process. The remarks regarding slaked lime are applicable here, except as to the quantity of the proprietary compound to be used, this, of course, being specified by the manufacturer.

Occasionally surface coatings have been employed with more or less success. Such coatings, however, should be composed of materials which are not affected by the free alkali in the cement which will saponify most oils.

PROPORTIONING AND MIXING CONCRETE

The fundamental principles governing concrete block construction, so far as relates to the proportioning and mixing of the ingredients, does not differ materially from that of ordinary concrete construction, and has been fully discussed in Arts. 13, 14 and 15.

Proportioning the Materials.—It is customary to fix arbitrarily the proportions of materials used for blocks (see page 137). When sand is employed for the aggregate, the proportions used vary from 1:2½ to 1:6, a very common proportion being 1:4. A strong and fairly impervious material is desired, to secure which requires a proportion of sand not to exceed 2½ or 3 parts. From 3 to 5 parts of gravel or broken stone may be used without decreasing the strength of the product.

Frequently the gravel or broken stone is omitted and as many as 5 or 6 parts of sand used. This is exceedingly bad practice and entirely incorrect in principle; the omission of the coarse aggregate should not permit the use of increased quantities of fine material. Gravel and broken stone with sand gives a denser mixture, and requires less cement than sand mixtures. It is a mistaken idea that sand will give a denser mixture than sand and gravel or broken stone mixtures. When gravel or broken stone with sand are used for the aggregate, leaner mixtures will give equal strength.

The proportions used in making true concrete blocks have also been arbitrarily fixed. These proportions vary from 1:2:4 to 1:3:6. A very common mixture consists of 1 part cement, 2½ parts sand and 5 parts gravel or broken stone. Sometimes a 1:3½:6½ mixture is used, but such a mixture is applicable only in the case of heavy blocks where a large percentage of very coarse aggregate can be used. For a high-grade, water-tight concrete block, a 1:2:4 mixture is generally used.

When facing is used, sand mixtures in proportions varying from 1:1 to 1:3 are used for the facing mixture.

The most satisfactory mixture of cement, sand, gravel or broken stone must be determined by experiment with the materials to be used, according to the principles stated in Art. 13, page 145, in order to secure the greatest possible density. The results thus obtained should be carefully followed in proportioning mixtures for all work. Chapter III of this work should be carefully consulted as to the method of determining the best mixture with the given materials.

A considerable proportion of coarse material is just as necessary

as in other kinds of concrete work, and gravel or broken stone should be employed with this point in view.

The addition of slacked or hydrated lime tends to make the block less porous (see page 522).

Proportion of Water or Consistency of Mixture.—In respect to consistency, practice classifies concrete mixtures for block manufacture into wet mixtures, medium mixtures and dry mixtures. The consistency to use will depend largely on the type of block machine to be filled. Some machines can handle a much wetter mixture than others. In other words, concrete block machines are designed specially to use one of the three mixtures.

For poured work sufficient water is used to render the concrete mass semi-fluid, so that it can be readily poured from a bucket into a mold. This mixture is used in all processes where the block or other member is subjected to neither tamping nor pressure, but acquires the form of the mold by its own settlement and attains rigidity by remaining therein. A great number of molds are necessary in this case to allow the concrete sufficient time to set before their removal, as the concrete must remain there until hardened. A wet mixture produces a superior block both in point of strength and waterproofing qualities, but a medium mixture as described below is by far the most extensively used. Castings in sand molds are made by the use of a semi-fluid concrete. Fine limestone screenings prove the most satisfactory aggregate for poured work, as sand and gravel usually settle too rapidly for very wet mixtures.

For blocks molded by pressure, a medium wet mixture is used. The pressure or thorough tamping causes free water to flush to the surface. This is by far the most satisfactory mixture to adopt and should be used for the body of all tamped or pressed blocks.

A dry mixture is necessary if the block is to be removed from the mold as soon as made, just enough water being added to give the concrete the consistency of moist earth. That is to say, by a dry concrete is meant a mixture that on being pressed in the hand retains its shape but does not discolor the hand. Such a mixture should never be used for the body of the block. Blocks made from too dry concrete will always remain soft and weak, no matter how thoroughly sprinkled after being taken out of the molds. A mixture too dry to secure the initial set of cement can never give a good block. Such mixtures must be avoided if good and reliable blocks are to be manufactured.

On the other hand, if blocks are to be removed from the machines as soon as made, too much water will cause them to stick to the plates and sag out of shape. There is also a danger of the aggregates setting out apart from the cement and spoiling the block when too much water is used.

It is possible, however, to so proportion the water as to secure the required density and hardening qualities, and still be able to remove the blocks at once from the molds. The mixture should be as wet as can be used without sticking to the molds and without sagging when the molds are removed. In other words, the aim should

always be to use as wet a mixture as can be conveniently discharged from the mold. A high proportion of coarse material allows the mixture to be made proportionately wetter without sticking or sagging. The proper consistency has to be determined by experimenting on the materials being used. The general rule to be followed is:

"Use as much water as possible without causing the blocks to stick to the plates or change shape on being removed from the machine or molds. The mixture should leave a steel trowel clean when dropped from it."

The proportion of water to be used is a matter of the utmost consequence, and has more effect on the quality and strength of the blocks than is generally supposed. The use of the correct proportion of water at the proper time is a fundamental principle of block making.

It is impossible to give a fixed percentage of the amount of water required, as this varies with the character of the materials, the moisture in the atmosphere, and other causes (see Art. 15, page 193). This amount of water is generally less than 10 per cent of the weight of the dry material or mixture. Usually about 8 or 9 per cent of the dry mixture by weight will be found satisfactory. An experienced block manufacturer can judge accurately when the right amount of water has been employed by squeezing some of the mixture in his hand. It should easily hold its shape upon relieving the pressure; if not, it is too dry. It should also moisten the hand when squeezed in it.

To secure uniform blocks in strength and color, the same amount of water should be used for each batch; otherwise, slight variations in the proportion of water make a marked difference in the quality and color of the blocks. When the proper quantity of water has been determined for any set of materials that quantity should always be accurately measured out for each batch.

Mixing the Materials.—Two methods of mixing the materials, first machine mixing and second hand mixing, are available in concrete block manufacture as in general concrete work (see pages 167 and 176). Machine mixing is very much to be preferred to hand mixing, and batch mixers should be used, because it is essential that only measured quantities of each kind of material are found in combination at every stage of mixing, else variations in quality and color will be inevitable. The time of mixing cannot be as well regulated with continuous mixers as with batch mixers. Good results, however, may be obtained in hand-mixed concrete.

Materials should be mixed in the dry state until the combination is uniform in color and the parts are perfectly combined. The proper amount of water is to be added and the mixing continued until the concrete is of an even color throughout and every particle coated with cement paste.

As in all other concrete work, thoroughness in mixing is necessary to success in concrete block manufacture. In fact, the thorough mixing of all the ingredients is one of the most essential things in block making. Art. 15 should be carefully read in this connection.

Theoretically, every particle of the aggregate must be cement-coated, and this can be effected only by mixing much more thoroughly than is common. The kind of mixing required to make superior concrete blocks involves something more than running the ingredients through a batch mixer and something more than shoveling for a given period of time in hand mixing.

The amount of water used for blocks to be removed from molds as soon as made is so small that it can be evenly distributed throughout the material only by careful and thorough mixing. If the thorough and even mixing is not strictly observed, damaging results will follow. Insufficient mixing will cause the blocks to be weak and unevenly colored.

Only enough concrete should be mixed at a time so that it can easily be worked up before the initial setting occurs; otherwise, it will weaken the block and especially prevent thorough consolidation. The size of batch to be mixed should not be of greater volume than can be consumed in 30 minutes, as the average cement takes its initial set within that time, and a block that is to be of good quality must be molded before the cement begins to set.

MACHINES USED FOR MAKING BLOCKS

A great variety of molding machines are in use for the manufacture of concrete blocks. They vary with respect to: (1) the method employed for compacting the concrete, i. e., tamping, compressing and pouring; (2) the consistency of the material used, i. e., dry, medium and wet mixtures; (3) the position occupied by the face of the block during the molding process, i. e., vertical-faced and horizontal-faced machines; and (4) the kind of blocks required, i. e., ordinary hollow blocks and staggered or two-piece blocks.

In one process the concrete is mixed to a damp consistency and tamped into the molds either by hand or by pneumatic or mechanical tamper. Other machines use a somewhat wetter mixture, that is, a medium or moderately wet mixture, and apply pressure mechanically. A third process consists in pouring wet concrete into molds. In the first two processes the concrete is sufficiently dry to enable the mold to be removed immediately from the block (the first process is to be avoided as mentioned on page 534), but in the last process the mold cannot be removed until the concrete is set.

In the horizontal-faced concrete block machines (the "face-down" or "down-face" machines), the face-plate forms the bottom of the mold; in the vertical-faced machines, this plate is held in a vertical position. Sometimes the face of the block is formed by the cover of the mold, instead of the bottom of the mold; in such cases it is a "face-up" machine or mold. The face-down machine is the more easily adapted to applying specially treated faces to blocks. If a vertical-faced machine is used, the special facing (consisting simply of rich mortar, which may be colored, waterproofed, etc., as mentioned below) is placed while the concrete forming the body of the block is kept back by a parting plate or other device. In the face-

down machine, the facing can be placed directly in the bottom of the mold, and the coarser body mixture be placed above it.

The machines for ordinary hollow blocks are made with horizontal or vertical cores, the horizontal core machines being rather better for making blocks with a special facing mixture as mentioned above. The machines for staggered blocks have cores placed so as to produce a staggered effect. The object of the staggering is to prevent the moisture having a direct passage through the wall by leaving an air space between the two faces of the block. Machines for so-called "two-piece" systems mold the pieces by pressure on a moderately wet mixture.

Principles of Block Machines.—Concrete block machines are all very similar in general principles, but differ in minor mechanical applications. The simplest machines are merely molds with removable sides, ends and cores, and there are many methods of combining and operating these elements.

In some cases the machine or mold is moved away from the block, rather than removing the block from the machine. Some machines automatically release the block from the mold, delivering it upon a base plate to a support in front of the machine, ready to be carried away. Other machines are equipped with mechanical devices for raising and lowering cores and blocks, for operating the removable sides and ends of the mold, for lifting and transporting the blocks, etc. This gives opportunity for the application of much inventive genius and the variety of machines is added to at least monthly, until now it is almost an impossibility to keep track of them.

Sand cores are used occasionally to take some of the excess water in the concrete and hasten the time of setting or hardening.

The tamping may be done by hand and by pneumatic or mechanical tampers, of which there are several designs on the market, handled in various ways. A few machines apply pressure to the blocks instead of the tamper, some by means of hydraulic presses, others by means of levers operated by hand or by machines.

Nearly all block machines have adjustable or exchangeable sides, so that face designs can be substituted for plain faces.

Many of the machines are so adjusted that the sides of a block can be faced with a richer mortar of the desired thickness. This gives a neater, smoother face to the block and makes it less pervious to water. If desired, this outer shell can be colored, giving a very fair imitation of natural stone without being expensive in coloring matter, or this shell may be waterproofed as mentioned below.

One ideal which all block-machine makers strive to attain is the elasticity in size and shape of their blocks. Most block machines attain this ideal to a greater or less degree. The forms and sizes of blocks are endless in their variety, each inventor having his own ideas of the best form and size of block. There is but little uniformity in the blocks on the market, and in fact in many instances there seems to have been an effort to make blocks which cannot be used with those made on any other machine.

Another ideal which all block-machine makers strive to attain is

to have their blocks amply strong and at the same time reduce the amount of material, which is accomplished by making the block hollow—this also makes walls which keep more equable temperature within the structure, and which aid in preventing moisture reaching the interior surface of the walls.

Molds.—Molds are made of wood, iron or steel, or in some systems of sand, and may be of three general types, depending on the position occupied by the face of the block. If the face is formed by the bottom of the mold, it is a "face-down" mold; if formed by one of the sides of the mold, it is a "side-face" mold; and if formed by the cover of the mold, it is a "face-up" mold.

Molds with solid sides can be used indefinitely, a number being required sufficient to keep the workmen busy until the cement has set and the molds can be removed to use again.

Some of the molds are fixed in size, fractional blocks being made by inserting plate partitions, necessitating a different mold for each size or shape of full-sized block. Others are equipped with adjustable beds on which various sizes and designs of side and end plates and cores can be operated. Still others are adjustable in all dimensions with the help of some extra plates.

According to several systems sand molds are used, which give a special texture to the surface of the blocks and regulate the amount of water automatically to the requirements of the cement in crystallizing. In one instance it is claimed that by using sand molds, a chemical is applied which hastens the hardening of the surface.

Face Plates.—There is a variety of face plates on the market, rock-faced, tooled and rubbed faces being the most common. If rock-faced blocks are to be made, several different patterns of face should be used so as to break the monotony in the finished structure. Rock-faced blocks are usually cast from natural stone, but such facings are inartistic, as the blocks are very evident imitations, and for this reason should be avoided, a plain face being much more preferable.

General Stipulations.—All machines should be solid and substantial in construction. They should be provided with attachments for making angle blocks of 90, 45 and 30 degrees.

The molds must be rigid and rigidly bolted, clamped or locked together. They must be so constructed that they can be removed or released without injury to the green blocks.

The platens or working plates on which the block is carried and stacked must be stiff enough not to spring under the load and can be easily gotten hold of for carrying without wrenching or tilting the green block.

Care of Molds, Etc.—Molds must be kept perfectly clean, thus making a clear cut impression each time. They should be wiped frequently with an oiled cloth to keep them smooth and prevent sticking. Care must be taken not to discolor the face of the block by using too much or too dirty oil. In this connection, see Art. 18, page 241.

There are very few plants in which the machinery is carefully cleaned and oiled at the close of the day's work, and yet these

are some of the most essential factors of success. If the machine is not properly cleaned and oiled, it will be impossible to release the block without cracking or chipping it. Not much time is required in cleaning and oiling, and if the work is carefully done (as it should be), a much better and much larger product will be the result than if the machinery is neglected.

DEPOSITING CONCRETE

As in all other concrete work, care in depositing is necessary to success in concrete block manufacture. By depositing is meant the process of filling the mold with the ingredients of which the block is to be made. This process is not so simple as might at first appear, and many of the qualities that the final block is to possess will depend upon the care displayed during the molding. The first part of Art. 25 should be carefully read in this connection.

Method of Depositing.—The method of depositing the material in the mold will vary according to the kind of mold used. If a "side-face" mold is used, the concrete should be placed in small quantities, being carefully tamped or otherwise compressed into the corners and around the cores. If the block is to be faced with a material different from that used in the body as described in the next section, a thin partition should be employed and the facing mortar placed between the partition and the face plate and the coarse material back of the partition should be tamped as the latter is gradually withdrawn, as described in Art. 41, page 386.

The method of depositing the material will be discussed more fully under the section "Compressing the Material" (see page 533).

FACING OF CONCRETE BLOCKS

As provision must be made for introducing a thin facing of different materials from the mixture used for the body of the block at time of filling the mold, it is well to consider here the general subject of facing.

There has been considerable opposition to facing concrete blocks with a finer and richer mixture than that used in the body of the block, being caused by the belief that it is impossible to put on a veneer facing of rich mortar that will not crack, peel, or separate from the body of the block. This apprehension has been based on the difficulty of securing an adequate bond between body and face, or on the unequal expansion of the differing mixtures. In practice, however, the theoretical inequality of expansion has not proved disastrous, and the securing of an adequate bond between the body and the face is merely a matter of method, as mentioned below.

Cinder concrete blocks should always have a sand mortar facing at least ½ in. thick.

Blocks are made with either a plain face, or of various ornamental patterns, i. e., tool-faced, paneled, rock-faced, etc., which is done by introducing the proper face plate in the mold (see page 530).

Materials for Facing.—The best quality of Portland cement should be used, and may be of either the ordinary or white cement.

The aggregate for the facing should be of fine sand, fine stone screenings, marble dust, or other suitable material.

Facing Mixtures.—The facing is usually made of a mixture of cement and fine aggregate, varying in proportions from 1:1 to 1:3, while the backing or body of the block varies from 1:3 to 1:3:6, as mentioned on page 525. Either a 1:2 or 1:3 facing mixture is recommended as possessing less liability to hair cracks than a richer mixture. The penetration of water may be effectively prevented by using a facing consisting of 1 part Portland cement to 2 parts fine aggregate. (See pages 387 and 425.)

Thickness of Facing.—The facing should be at least ½ in. thick.

Colored Facing.—A more pleasing appearance may be given to the block by introducing a colored facing mixture in imitation of natural building stones. To secure permanent results colored sand or stone should be used, as mentioned in Art. 42, page 390, but the addition of coloring matter to the facing mixture will produce a similar result as mentioned on page 391.

If coloring matter is used only mineral coloring, rather than chemical, should be used, as the chemical colors may injure the concrete or fade. Even with the use of any coloring matter there is danger of the colors fading, and if too much coloring matter is added, the strength of the concrete may be affected.

In using coloring matter with the facing mortar, the color should always be mixed with the cement dry, before any sand or water is added, as mentioned on page 395. The mixing should be thorough, so that the mixture is uniform in color. After this mixing, the combination is treated in the same manner as clear cement. Art. 15 should be consulted as to the proper manner of mixing the mortar.

In coloring the facing mixture the wet mortar should be colored several shades darker than that desired in the finished face of the block, as the wet mortar looks darker to the eye than it really is, owing to the gloss of the water. Care must be taken not to get the facing mixture too dark, as this will make the concrete blocks contrary to nature. All natural stones are of a light color or shade, and therefore, in making a concrete block it should be given tone rather than color.

Waterproof Facing.—Art. 48 should be consulted in this connection.

Mixing the Facing.—The mixing of fine facing is a more delicate operation than the mixing of the concrete for the body of the block and must be done separately. The operation involves the careful screening of the fine aggregate and the addition of the cement, together with whatever coloring matter may be selected. It is essential that all the material be thoroughly mixed dry, the cement and coloring matter being first carefully mixed as mentioned above, and then the mixture slightly dampened.

The facing mixture should be mixed to a dry consistency, as it is unnecessary to make the facing mortar as wet as the body of the

block, because reliance may be placed upon the surplus water in the block to permeate the face by capillary attraction. There is an exception to this rule where a waterproofing compound is used. In such cases the waterproofing ingredient will not permit the water from the block to penetrate the face, and it will be necessary to mix the facing mortar with the proper amount of water, in order to insure proper crystallization.

In mixing, the facing must not be allowed to become lumpy and the wet mixture should be screened, if necessary, immediately before it is used. There is a tendency for the facing mortar to ball up into little balls after being wet and mixed, owing to the fineness and richness of the mixture. This tendency of the material to form lumps or little balls must be overcome by rescreening the facing mortar immediately before using, as mentioned above.

A little more water than usual should be used in the body of the block so as to insure the moisture staying in the facing, except when the facing has been waterproofed, as mentioned above.

Placing the Facing.—The essential points of successful facing are two:

1. The face and the body of the block must be made at one simultaneous operation, no interval of time being allowed to elapse between the making of the body and the facing of the block.

2. The facing must be so embedded into the coarse concrete that it becomes an integral part of the block, and there must be no distinct line of cleavers between the facing and the body of the block. It is of the utmost importance that the facing and the rest of the block be thoroughly bonded together, so that there will be no distinct line where one joins the other. Thus only may an indestructible bond be secured.

In the manufacture of blocks with a facing coat only those methods should be used in which the body of the block is placed at the same time as the face, and the tamping or pressing of the material in the mold bears such a relation to the facing coat that the face will become firmly joined to the body of the block, so that it can be removed only by the destruction of the block. Three methods are employed for placing the facing mixture:

1. As previously explained (see page 528), in a "side-face" machine or mold, the facing mixture should be deposited by use of a thin partition or backing board, unless the mold is filled with a tilting device to obviate the use of a partition; the body of the block is then put in and tamped as the partition is withdrawn. Care must be taken to avoid a seam or cleavage plane between the two mixtures.

2. In a "face-down" or "down-face" machine or mold, the facing mixture should be deposited first on the face plate to the desired thickness, tamped, and the body of the block then placed upon it and carefully tamped. The facing mixture must be well bonded with the concrete backing by tamping the two together.

3. In a "face-up" machine or mold, the facing mixture should be placed last. The facing must be deposited before the backing

takes its set. Direct compression of the face must be obtained. This method is usually employed in pressure machines, the pressure plate being the facing plate of the mold.

Face Finishes.—The methods of treating concrete surfaces described in Arts. 43 and 44, should be consulted in this connection. In no case should the face be troweled, either before or after molding. Troweling brings neat cement to the surface, resulting in hair cracks, etc. (see page 484).

Crazing or hair cracks sometimes appear on faces because there is an excess of cement on the surface. Brushing of the surface at the exact stage of hardening which is best will improve the faces in this regard.

COMPRESSING THE MATERIAL

Immediately following the depositing of the material in the mold, proper attention must be given to its condensation, in order to obtain satisfactory strength, density, and impermeability in the block. The various particles in the composition of the block must be brought into such intimate contact by proper condensation that the cement will be enabled to perform its duty as an adhesive agent, uniting the loose mass into a firm unit. No block can come from the mold strong, dense, and impervious unless it has been condensed to such a degree that air is practically eliminated.

There are three general methods of securing this condensation, viz.: tamping, compressing, and pouring; but no matter what method is employed, the condensation must be very thorough.

Tamping.—In the tamping method, which is the one most in use at the present time, the material in a damp condition is thoroughly tamped by hand or by pneumatic tampers as it is put into the mold. This method was adopted by the early advocates of concrete blocks as the most readily apparent method, which was then the common method used in general concrete work. The one-piece block in multitudinous forms is the one generally used in the tamping system.

If the tamping method is employed, care must be taken to avoid the use of too wet or too dry a mixture and to secure a sufficient amount of compacting. This method is not adaptable to the use of coarse material mixed wet, which is now generally accepted as better for block work than the dry-sand mixture of the early days. A comparatively dry mixture of cement and sand will pack under the blows of a tamper in a manner impracticable in a wet mixture or in one containing a considerable portion of coarse aggregate. In the coarse mixture, the blows of the tamper often dislodge adjoining portions of the block, while in a wet mixture there is always a tendency of the concrete to squash under the blows.

The ease with which a good-appearing block can be made with little tamping has led to much poor work by this method. Thoroughly satisfactory results may, however, be obtained, but the tamping must be done in a more industrious and more intelligent manner than is common in many concrete block factories, in order to obtain such results.

The tamping should be done from the bottom up as the mixture is filled into the mold. The mold should not be half filled before beginning tamping, but should be filled layer by layer, the layers being of such thickness that the full force of the tamping blow is exerted on every portion of the block. The concrete should be placed in the mold in layers about 3 in. thick. Tamping should begin immediately upon placing of the first shovelful and should be continued until the mold is filled, care being taken to thoroughly tamp each addition but not so as to produce lines of stratification. At least four such fillings and tampings should be given each block.

To insure a block of the same density throughout, the tamping must be thorough and should be continued until water appears at the top of each layer. Especial care must be taken to see that the edges and corners are as thoroughly rammed as the center of the block. In other words, the tamping should be so regulated that the density shall be uniform in every part of the block and relatively equal in each block. The tamping of each layer thoroughly so that the bottom of the block will be of like density with the top will insure a minimum of air spaces and voids.

The tamping must be conscientious and thorough, and unless the tamping is even and uniform there will be soft spots in the block.

The material should be tamped with a tamper having a small face, and short, quick, sharp blows should be struck. The tamping is generally done with hand rammers. Of late the tamping of the material by means of power tampers has come into extensive use. Pneumatic tampers, operated by an air-compressor, are used successfully. A single pneumatic tamper possesses no advantage over a hand tamper except in speed, force, and endurance.

Compressing.—The material, which is of a medium wet consistency, may be condensed in the mold by pressure secured by toggle joints or other mechanism and by hydraulic pressure. In either case, the mold is filled and only one pressure is made on the entire block, vent holes being provided for the expulsion of air, which should never be allowed to close. The minimum pressure should be at least 350 lbs. per sq. in. of the face surface of the block.

The hydraulic presses commonly used give an ultimate pressure up to 200 tons, and are more accurate than mechanical presses, as the amount of pressure is shown exactly by a gauge attached to the machine, and is the same regardless of the amount of material in the mold. They are, however, slower in action than mechanical presses, owing to the time required in pumping up the cylinders. This lack of speed in operation may be overcome by molding several blocks at one time, as the pressure can be obtained much greater than is required for a single block.

The mechanical presses are usually rated to give each block a pressure of 50 tons, which is more than ample for the compression of an ordinary block. With the toggle joint machines, the pressure is more or less indeterminate, depending on the amount of material put into the mold.

The method of filling the mold and then applying the pressure

as mentioned above is not the best practice, unless the pressure is applied to comparatively thin molds or layers. If the compression of thick layers is attempted, the materials have a tendency to arch and are not compacted at any considerable depth from the surface. The two-piece block is the most satisfactory one to use in the pressure system, the load being applied to the surface of pieces having no great thickness. The one-piece block, however, can be made by the pressure system.

Pouring.—In the condensation method known as pouring, a wet mixture is poured into a mold of metal or of sand, and the material allowed to condense by its own settlement; that is, it is allowed to attain a minimum volume by gravity. The one-piece block is the block usually used in the pouring system of work.

The material should be mixed so wet that it is easily poured into the mold and readily acquires the form thereof, the mold being filled in one pouring if size permits. The material should remain in the mold until it gains sufficient rigidity to maintain its shape without support.

Great care must be taken to see that the mold is completely filled in all parts, and particularly in the angles and corners, and that no air holes are in the material. The mixture must be thoroughly stirred and churned or puddled (see Art. 25, page 296) to eliminate air voids, prevent arching and fill compactly corners and edges of the mold.

The pouring process is much better adapted to ornamental concrete than to concrete building blocks (see Art. 54). Concrete ornaments are usually manufactured either in sand molds or in plaster molds, in which glue negatives are used if there is to be an undercut in the ornamental parts.

REMOVING CONCRETE BLOCKS (OFF-BEARING)

The delivery of a block and its off-bearing may seem to be matters that are too trivial to deserve special instructions; yet blocks are very often injured by jars in handling, especially in taking out of the mold and in setting in racks, also on cars running on a rough track.

Sensitiveness of Freshly Molded Blocks.—The off-bearer may be careless at times, but very often he is required to carry a block whose weight, while not heavy in an ordinary sense, is too heavy to be handled with the care due to freshly made block. A dry mixture block when taken from the mold has no cohesion except the tamping density and has to be removed and handled with great care to prevent injury.

The point to bear in mind is that a freshly molded concrete block is very sensitive and the necessity of adapting the discharge and handling to this sensitiveness, so that the block will not be injured in any way before the initial set.

Cracks, and Damaged Corners or Arrises.—The block must be removed from the mold to the curing skids without cracking it or injuring corners or arrises. It is in the careless removal of the block

from the mold that corners are knocked off, that patches are pulled from the face, that incipient cracks are started, and that various irreparable injuries are done to the block.

Arrises and corners, if not badly damaged, can be repaired, but a block which is cracked cannot be satisfactorily repaired; it should be broken up and the material thrown back and molded over.

The faces and edges of blocks should show no marks of cement sticking to molds or of careless marring.

Removing Molds from Blocks.—The mold must not be removed until the concrete has thoroughly set and is strong enough to do without the support of the mold.

The time of safe removal of the block will depend upon the consistency of the mixture; the size, shape and weight of the block; weather conditions and other factors (see Art. 19, page 245).

A block can be removed from the mold as soon as the cement has set if care is taken, but the block cannot be handled for some time, depending on conditions.

Removing Blocks from Platens.—The blocks should be removed from the machine or mold on a steel plate or pallet. All blocks made by the medium wet or medium dry process should remain on the pallet or platen at least twenty-four hours. The block should be removed from the platen by tipping it onto a sand or a sawdust cushion. Care must be taken to loosen the platen by tapping it lightly and not by prying or wrenching.

CURING CONCRETE BLOCKS

After molding the next process in the proper making of concrete blocks is the curing by which is meant more than aging, and something that is entirely different from drying. The molding of the block is only the initial process of its manufacture. The curing period, which follows, is the most important in the manufacture of concrete blocks, and is the most critical period in determining the quality of the finished block, being the critical stage of transformation in which a mass of cement, sand, gravel or broken stone, and water becomes a hard, dense, and enduring unit suitable for building purposes.

The greater emphasis must be placed on curing, because it is so easily slighted. Many block makers consider that the block is made as soon as it comes out of the mold and very little attention given to the proper curing of it. A block badly cured will lose all the good qualities imparted to it by careful manufacture.

There is a common belief that blocks should be allowed to dry out for a week or two after molding. This notion is erroneous, for the essential element in curing is moisture, but its application is governed by certain conditions that must be carefully observed.

Concrete blocks may be cured by water or by steam, the water curing requiring very special care.

Protection from Sun and Wind.—Blocks should be molded and stored for curing so that they cannot be acted upon by direct rays

of the sun or by warm air currents. It is absolutely necessary to protect the blocks from both sun and wind and during the sprinkling period. In general, the whole idea of curing may be summed up in one word—Uniformity. Under no circumstances should blocks be made under the direct rays of the sun, nor should blocks be exposed either to sunshine or dry winds while curing. Exposure to sun and wind will ruin the appearance and impair the strength of the blocks.

Blocks as soon as taken from the molds should be placed in a curing room or shed, which should be built so as to exclude all sunshine or draughts of air, as uniform conditions and protection from the sun's rays are equally necessary for all blocks. Ample curing sheds must be provided to care for blocks until they cease to require sprinkling. In case this is not convenient, the blocks may be carried outside after setting and covered with canvas, straw or other covering that will preserve the moisture and shield the blocks from the sun and wind.

Blocks exposed to the sun or to warm air currents, causing variation in contracting of the face and thus producing hair cracks, should not be accepted.

Protection from Sudden Temperature Changes.—The blocks must be stored for the first few days where the changes in temperature will be as slight as possible. Crazing or hair cracks appear on faces of blocks because blocks are subjected to changes in temperature before the surfaces are fully cured.

Protection during Freezing Weather.—The curing of blocks in winter has presented a problem so serious that many plants have ceased to operate during freezing weather. This, however, is unnecessary, if the curing sheds be heated by large stoves or salamanders as described in Art. 33 or the blocks covered with manure, straw, etc., mentioned in the same article.

Blocks should be protected from freezing for at least a week after molding.

Stacking Blocks for Curing.—Green blocks should be stacked for curing in a horizontal position on unyielding supports and so as not to touch or to bring any weight on adjacent blocks. This may be arranged by placing lath between them, the idea being to prevent discoloration by contact and to insure a free circulation of air on all sides of each block. The blocks must not be allowed to rest against one another, as it is absolutely essential that a free circulation of air be allowed around them, lath being placed between the tiers of blocks.

Sprinkling Blocks.—It is very important that the block be constantly, uniformly and adequately moistened during the curing period that follows its molding, so that the final set may take place under the most favorable conditions, thus insuring the greatest strength. A block must cure uniformly.

Plenty of water is absolutely necessary to the process of setting, and the block must be kept thoroughly wet in order to secure that thorough crystallization essential to ultimate strength. The primal requisite in proper curing is water and plenty of it. The process of

setting or hardening in the concrete goes on for a great many days, and crystallization, upon which depends the strength of concrete, cannot go on without the presence of a sufficient amount of water to supply moisture to all parts of the block. Apply water in abundance.

The sprinkling, particularly while the block is still soft, should be done by means of a gentle spray from a hose nozzle which will not "wash" the concrete. A hose and spray will reach the blocks if piled as specified above. In large plants, the introduction of pipes fixed over the blocks will eliminate the expense of a hose tender. Blocks should be freely supplied with water by sprinkling.

In summer the blocks should be gently sprinkled as soon as possible after making without being defaced; that is, the sprinkling should begin as soon as the cement is hard enough not to wash, usually from 3 to 12 hours after molding. No stated time can be given for sprinkling, as all depends on the atmospheric conditions. Some days it can be begun in two hours and at other times five to ten hours must elapse before the water can be safely applied. The sprinkling should continue for at least ten days.

Blocks should be sprinkled at regular intervals and so frequently that no drying takes place. They should never be allowed to become dry or turn white during curing. In other words, a block should never be allowed to dry out on the sides before the center is thoroughly cured. The block must be kept uniformly damp in every part and at all times, a gentle spray being used to reach every part of the block. The slower the drying of the block, the harder and tougher will it become. An early drying of the block, on the other hand, will have a tendency to dry out the corners before the initial set is fully completed, leaving them with little strength and likely to crumble at a touch. To avoid this early drying out necessitates sprinkling so frequently that the edges of the block will not become partly dry, for if the concrete dries out immediately after making, the action of the cement is deadened and the edges and corners are weak and crumbly.

As soon as the surface of a block begins to turn white it is a sure sign that it needs water. Too much water cannot be used. Sprinkling should be done regularly and in proper amount. No set rule that will govern all conditions of climate and temperature can be given. The hotter and drier it is, the more frequent must be the sprinkling, usually three times daily for the first week or ten days. A sand floor kept thoroughly wet may be used to insure a damp atmosphere. The blocks should preferably be covered with some material that will serve in a measure to retain moisture. Canvas, clean hay, or straw will usually answer the purpose. Any of these materials will maintain a uniform condition of moisture in the air immediately surrounding the blocks. (See page 336.)

Concrete blocks, if molded with a medium dry mixture, should be kept saturated by constant sprinkling for a long period after molding, owing to not having enough mixing water to enable the cement to set and harden perfectly, and this deficiency has to be

supplied by sprinkling. Plenty of water for at least ten days is what the blocks need after the first sprinkling is given, in order to receive the proper curing.

Efflorescence or the appearance of a white or yellowish coating on a block sometimes takes place when it is periodically saturated and then dried out. Blocks placed directly on the ground are most liable to show this defect. This efflorescence is due to the diffusion of soluble sulphate and alkali to the surface, and will usually disappear in time (see Art. 31).

Blocks treated with varying degrees of moisture, causing variation in contracting of the face, and thus producing hair-cracks, should not be accepted.

Curing Period for Blocks.—The duration of the sprinkling period depends on the consistency of mixture used. It should never be less than one (1) week, and from that to about three (3) weeks.

Blocks made by a dry mixture should be carefully sprinkled for about 20 days. Blocks made from a medium mixture 7 to 10 days. When a wet mixture is used, little water will be necessary in curing, but uniform conditions must be maintained and the block sheltered from the direct rays of the sun and from hot air currents as mentioned above. After the sprinkling has ceased the blocks should be exposed to the atmosphere and allowed to age several weeks longer before going into the building.

Freshly made blocks should never be used in a building, as they shrink considerably. Blocks are often rushed into the wall too quickly, and careless handling mars their appearance. If they are built in a wall while green, shrinkage cracks will be apt to occur in the joints. The blocks should be cured for at least 30 days before they are removed from the storage yards for use in buildings. Blocks generally shrink about 1/16 in. in length during the first month of the molding. This shrinkage would cause cracks in any finished structure erected with green blocks.

It is well to bear in mind that the longer a block is cured, the harder and better it will become.

Steam Curing.—Where steam curing process is to be employed, rooms should be provided which can be closed up fairly tight and exhaust steam or live steam turned on from pipes running under the floor. Dry steam should under no circumstances be used.

The blocks should be kept in moist air for at least 24 hours after molding, when they should be placed in a moderately tight room into which exhaust steam of low pressure is turned, not more than 5 lbs. pressure being used at any time on the pipe conducting this steam. The blocks should remain in the steam room for at least 36 hours, after which they should be thoroughly sprinkled with water and properly protected from the sun and wind for a further period of at least 48 hours. Curing by this method shows results equal to 10 days by sprinkling, and the blocks are usually much lighter in color. Warmth accelerates the setting of the cement, and the steam supplies enough moisture for a perfect crystallization.

Steam curing not only facilitates winter work, but effects a considerable saving of storage room, because of the shorter time required to protect the blocks.

Blocks subjected to a steam bath as described above can usually be used after 4 or 5 days.

Preparations for Hardening Blocks Quickly.—There are now several preparations on the market for hardening concrete blocks quickly. The composition and mode of action of these preparations should be fully known before they are used in important work. If the substance acts by setting up a favorable chemical action and crystallization and hastening it, there can be no objection to its use, provided, of course, there is not a future reaction. On the other hand, if the action is produced by a chemical which ultimately produces a disintegration of the cementing substances in the concrete, then the ability to handle blocks quickly is gained at too great a cost of reduction in durability to warrant the use of such a substance. Some of these substances also contain matters which are soluble in water and produce efflorescence (see Art. 31) and discoloration.

STANDARD METHOD OF TESTING

The following methods of testing concrete building blocks have been taken from the Standard Specifications for Cement Hollow Building Blocks as adopted January, 1908, by the National Association of Cement Users, Philadelphia, Pennsylvania.

Approval Tests.—All tests required for approval shall be made in some laboratory of recognized standing, under the supervision of the engineer of the bureau of building inspection, or the architect or engineer in charge, or all of these. The manufacturer may be present or represented during said tests, if he so desires. Approval tests are made at the expense of the applicant.

Samples or Test Pieces.—For the purposes of the tests, at least twelve (12) samples or test pieces must be provided. Such samples must represent the ordinary commercial product and may be selected from stock by the bureau of building inspection, or, in the absence of such a bureau, by the architect or engineer in charge. The samples may be tested as soon as desired by the applicant, but in no case later than 60 days after manufacture.

In cases where the material is made and used in special shapes or forms too large for testing in the ordinary machines, smaller sized specimens shall be used as may be directed.

Weight per Cubic Foot of Material.—In addition to the tests required for approval, the weight per cubic foot of the material must also be obtained and recorded.

Manner of Making Tests.—Tests shall be made in series of at least three (3), except that in the first tests a series of two (four samples) are sufficient.

Transverse tests shall be made on full-sized samples. Half samples may be used for the crushing, freezing and fire tests. The

remaining samples are kept in reserve, in case duplicate or confirmatory tests be required. All samples must be marked for identification and comparison.

Transverse Test.—The transverse test shall be made as follows: The samples shall be placed flatwise on two rounded knife-edge bearings set parallel 7 in. apart. A load is then applied on top, midway between the supports, and transmitted through a similar rounded knife edge, until the sample is ruptured. The modulus of rupture shall then be determined by multiplying the total breaking load in pounds by 21 (three times the distance between supports, in inches) and then dividing the result thus obtained by twice the product of the width in inches by the square of the depth in inches. $R = 3Wl/2bd^2$. No allowance should be made in figuring the modulus of the rupture for the hollow spaces.

The modulus of rupture for concrete blocks at 28 days must average 150 and must not fall below 100 in any case.

Compression Test.—The compression test shall be made as follows: Samples must be cut from blocks, so as to contain a full web section. The sample must be carefully measured, then bedded flatwise in plaster of Paris, to secure a uniform bearing in the testing machine, and crushed. The total breaking load is then divided by the area in compression in square inches, no deduction to be made for hollow spaces; the area will be considered as the product of the width by the length.

The ultimate compressive strength at 28 days must average 1,000 lbs. per square inch, and must not fall below 700 in any case, according to the specifications of the National Association of Cement Users, as mentioned at the beginning of this section. Some specifications require that the minimum compressive strength of any block shall be 1,600 lbs. per square inch of solid material subjected to pressure in the testing machine, and the average compressive strength of any series of blocks tested shall not be less than 1,800 lbs. to the square inch of such solid material.

Absorption Test.—The absorption test shall be made as follows: The sample is first thoroughly dried to a constant weight, at not to exceed 212° F. The weight must be carefully recorded. It is then placed in a pan or tray of water, face downward, immersing it to a depth of not less than 2 in. It is again carefully weighed at the following periods: 30 minutes, 4 hours, and 48 hours, respectively, from the time of immersion, being replaced in the water in each case as soon as the weight is taken. Its compressive strength, while still wet, is then determined at the end of the 48-hour period, in the manner mentioned above for Compressive Test.

The percentage of absorption (being the weight of water absorbed divided by the weight of the dry sample) must not average higher than 15 per cent and must not exceed 22 per cent in any case. The reduction of compressive strength must not be more than 33 1/3 per cent, except that when the lower figure is still above 1,000 lbs. per square inch the loss in strength may be neglected.

Freezing Test.—The freezing test shall be made as follows: The

sample is immersed, as described for Absorption Test, for at least 4 hours, and then weighed. It is then placed in a freezing mixture or a refrigerator, or otherwise subjected to a temperature of less than 15° F. for at least 12 hours. It is then removed and placed in water, where it must remain for at least one hour, the temperature of which is at least 150° F. This operation is repeated ten (10) times, after which the sample is again weighed while still wet from the last thawing. Its crushing strength should then be determined as called for in the section above on Compression Test.

The freezing and thawing process must not cause a loss in weight greater than 10 per cent, nor a loss in strength of more than 33 1/3 per cent, except that when the lower figure is still above 1,000 lbs. per square inch the loss in strength may be neglected.

Fire Test.—The fire test is made as follows: Two samples are placed in a cold furnace in which the temperature is gradually raised to 1700° F. The test piece must be subjected to this temperature for at least 30 minutes. One of the samples is then plunged into cold water (about 50° to 60° F.) and the results noted. The second sample is permitted to cool gradually in air and the results noted.

The fire test must not cause the material to disintegrate.

LAYING CONCRETE BLOCKS

The proper placing of concrete blocks in a wall is just as important as their proper manufacture, as it is a factor that determines the ultimate efficiency of this class of construction and whose neglect operates to vitiate every good quality of well-made concrete blocks.

Composition of Mortar.—The mortar for laying concrete blocks should be composed of 1 part Portland cement to 3 parts of coarse sand. Sometimes a certain portion of slaked lime or of commercial hydrated lime (see Art. 48, page 428) is added to the mortar when mixing. If this plan is adopted a mortar consisting of 1 part Portland cement, 1 part of thoroughly slaked and pulverized lime, and 3 parts of sand should be used. This will prevent the mortar from becoming brittle, making it spread well and work easily under the trowel. (See pages 394 and 522.)

A reliable waterproofing compound may be added to mortar for laying concrete blocks (see Art. 48). This will prevent moisture from penetrating a wall at the mortar joints.

Very often ordinary lime mortar is used in laying blocks which is so commonly employed in bricklaying. This practice should be avoided.

Thickness of Mortar Joints.—The concrete blocks should be laid in a 3/8-in. bed of cement mortar and a 3/8-in. layer of mortar placed between the ends of abutting blocks. A large number of concrete block buildings upon close inspection show joints varying from less than 1/4 in. to more than 1/2 in. There is no valid excuse for such variations, as the joints should be of uniform thickness throughout the wall.

Mixing Mortar.—Only such quantities of cement mortar should be

mixed at a time as will be used within 30 minutes, as it starts to harden very soon after mixing. (See Art. 15.)

Laying Concrete Blocks.—It should be remembered that it is necessary in all cases to immerse the blocks in water immediately before laying, so that they will be thoroughly wet when laid in the wall. Otherwise the dry surface of the block will absorb moisture from the mortar, making it very weak and easily penetrated by water. It is very important that there should be a firm bond between the blocks and the mortar, which can only be accomplished by drenching the blocks with water just before laying them; otherwise the result will be "dead" mortar in which the cement is only partly crystallized and no adhesion.

Before laying the first layer of block the top of the foundation must be carefully leveled up if it is not so already.

The courses should begin at the corners and be laid toward the middle of the wall.

The blocks must be laid level and kept in perfect alignment. In order to secure good alignment the blocks should be laid strictly to a line stretched over the outer edge of the wall on the same level with the top of the blocks being laid. The wall should be tested often by placing the plumb level against it to see that it is perpendicular.

Pointing should be done the same way as in laying ordinary brickwork.

Care must be taken not to allow any mortar to run down on the face of the wall, unless a non-staining cement is used.

Concrete blocks should be molded to fit in their destined place in the building. Otherwise, it not only wastes blocks by cutting them, and takes entirely too much of the mason's time, but results in poor workmanship, as the pieces never fit as well as a block made for the place. Freshly made blocks may be cut with a large knife, if only a few blocks of a special size are wanted.

Art. 56. Concrete Fence Posts

A concrete fence post may be constructed in advance and put in place after it has properly hardened. Posts may also be molded in place, but the length of time which they must stand before the removal of the forms requires the use of a large number of forms. Posts of the "cast-and-place" type only will be considered in this article, though most of the instructions or directions are applicable to posts molded in place.

It is customary to make concrete posts slightly larger than the wooden posts which would be used for the same purposes. They are usually made with a square or rectangular cross-section, as posts of cross-section approaching a square form are easiest made and most suitable for fencing. The size may be 5 or 6 in. square at the bottom and 4 or 5 in. square at the top, the average cross-section being about 25 sq. in. The length depends upon the height desired above ground, and the amount to be placed under ground depends upon the depth of the frost line, which is sometimes 3 or 4 ft. For

farm or division fences the length of posts may be about 7 ft., allowing 3 ft. of this to set into the ground.

Various methods of reinforcing fence posts are in use and recommended by the various manufacturers, depending on what is most easily and economically available. The reinforcement should be strong, light, and rough enough to permit the mixture to get a firm grip upon it, being at the same time very rigid, with little or no tendency to spring or stretch. For ordinary conditions, wire or light rods may be used, one rod being placed near each corner. This is probably the most efficient arrangement. Usually $\frac{1}{4}$-in. rods are placed in each corner. Scrap iron may often be used to advantage. For posts where a dry concrete is used, it seems advisable to use some sort of mechanical bond between the reinforcing and the concrete, i. e., a deformed bar.

Concrete Materials.—Extra precaution should be used in the selection of materials for concrete fence post construction, as it is desirable that the post be made as light and as strong as possible. Only the best grades of Portland cement should be used, and they should comply with the Standard Specifications of the American Society for Testing Materials, adopted June, 1904, together with subsequent changes and amendments. (See also Art. 4, page 43.)

The sand, gravel or broken stone and water should comply with the requirements stated in Arts. 8, 9, 10 and 12. The pebbles or broken stones should not be too large, as they will interfere with the proper placement of the reinforcement. Stone or gravel should pass a $\frac{1}{2}$-in. square mesh. Soft sandstone, soft limestones, slates or shales must be avoided. Granites, hard limestones and clean gravel are the best.

Proportioning Concrete.—The concrete should be mixed with Portland cement in about the proportions of 1:2$\frac{1}{2}$:5, gravel or broken stone under $\frac{1}{2}$ in. being used. In cases where the aggregate contains pieces smaller than $\frac{1}{4}$ in., less sand may be used, and in some cases it may be omitted altogether. Sometimes sand and cement are used in the proportions varying from 1:3 to 1:5, but it is better practice to form a true concrete in the proportions mentioned above.

Mixing Concrete.—A mixture of a wet consistency is recommended on the ground that it fills the molds better and with less tamping than if mixed dry. Posts made of wet concrete are said to be a little over 25 per cent stronger than tamped posts of the same size, mixture and reinforcement; they are also better able to withstand the action of frost.

Do not mix more concrete than can be used in 30 minutes. For methods of mixing concrete, see Art. 15.

Forms for Fence Posts.—Posts may be molded either in a vertical or horizontal position, the latter being the simpler and better method, and is the one most used. Various molds have been made and are on the market, all of which appear to be more or less satisfactory.

Forms are easily made singly or so as to mold several posts at once. Such forms may consist of two end pieces having notches which hold in place the longitudinal boards, cross-pieces or hooks

being provided to prevent the longitudinal pieces from bulging. To avoid sharp edges, which are easily chipped, triangular or beveled strips may be placed in the bottom of each mold along the sides, and when the molds have been filled and properly leveled off, similar strips may be inserted on top. It is not necessary to carry the bevel below the ground line.

Care must be taken to provide a substantial platform or molding bed for the posts in a manner similar to that described on page 559 for concrete piles.

Reinforcing Fence Posts.—The reinforcement should be placed in the post as near the corners as possible. In order that the reinforcement may be properly held and protected by the concrete, it should be placed from 3/8 to 3/4 in. from each side.

Attaching Fence Wires to Posts.—To provide a means for fastening the fence wires the simplest and most satisfactory method is to use a long staple or heavy bent wire well embedded in the concrete, being twisted or bent at the end to prevent extraction. Care must be taken to see that the staples or bent wires are put in their proper positions when the concrete is placed in the molds. For other methods of fastening fence wires to posts, see page 547.

Concreting Fence Posts.—Great care in tamping or puddling is necessary to insure the corners of the mold being well filled, and if this detail is not carefully watched, the reinforcement, being exposed in places, will be subject to rust. The wires or rods must in all cases be well covered at sides and ends or they will corrode. The concrete must be thoroughly compacted.

Removing Forms from Posts.—If a dry concrete has already been used, the ends and sides of the mold may be removed immediately; if the concrete was wet, the ends and sides should remain in place about 24 hours.

Removing Posts from Molds.—Posts may be removed from the molds a day or two after being made. In removing the posts from the molds great care must be taken not to allow the posts to sag or crack. Green posts should not be carried on the pallets or molding beds by taking hold of the ends, as the springing of the board might break the bonding in the middle, thus causing defects. A post may be cracked in handling and still be fit for service, but it cannot be considered to be as valuable as an uncracked one. Care must be used in handling green posts, or cracked posts will result. Carelessness in handling green posts frequently results in the formation of fine cracks, which, though unnoticed at the time, give evidence of their presence later in the failure of the posts.

There are two general methods of removing the posts from the molds. The first method consists in laying the molds with the posts in them on a level bed of sand or sawdust. The mold is then turned upside down and the post allowed to settle into the sand or sawdust. The mold is next removed and the post allowed to remain undisturbed for several days. When the post is sufficiently strong it is placed in an upright position, to be cured as described below.

The second method consists in removing the posts from the mold

while in an upright position, the post being allowed to lean against a wall or some other support. In this case only one handling is necessary. Care must be taken to have the bottom of the post close to the wall, as it is very likely to break if not in a very nearly upright position.

Although a post may be hard and apparently strong when a week old, it will not attain its full strength in that length of time, and must be handled with the utmost care, otherwise a cracked post will result.

Curing Fence Posts.—For at least a week after being removed from the molds the posts should be thoroughly wet down twice a day, and in summer protected from the sun by tarpaulins. The most favorable conditions for conserving the moisture consist in curing the posts in a shed where the wind does not strike them. Under these conditions neither the sun's rays nor the wind has a chance to dry out the posts too rapidly. Posts are sometimes required to be sprinkled every day for at least 30 days after being removed from the mold. (See pages 335 and 538.)

If possible, the posts should not be set until they are about 2 months old.

Handling the Posts after Curing.—After the posts are cured and ready to set they should be moved from the yard or curing shed and hauled to the fence line in a wagon having a strong, rigid bed, the bottom of the wagon being covered with a layer of straw to prevent breakage. Not more than three or four layers of posts should be placed in the wagon, depending upon road conditions.

In handling and setting, care must be taken not to drop the posts. It must not be expected that a concrete post will stand the degree of rough handling which can be given a wooden post. Some degree of care must be used in handling them, or cracked posts will result. The weight of the post places unnecessary stress upon the different parts, and in case it is dropped there is danger of it being cracked or destroyed.

Methods of Fastening Fence to Posts.—Various devices have been suggested for attaching fence wires to concrete posts, but these are mostly patented. The object of these devices is to secure a simple and permanent fastener or one admitting of easy renewal at any time. A few of the various methods of fastening the fence to the post in use at the present time are as follows:

A piece of copper or galvanized wire may be laid across the face of the post at the proper space about 1 or 1½ in. deep and projecting from either side several inches. These ends are twisted about the fence wire and will hold it in place. Should one end break with many changes of twisting and untwisting, the other is still left for use.

Holes may be bored at the proper places in the molds to correspond to the spaces of the wire and so as to be in the middle of the posts. Into these set ¼-in. pins; build around them; remove them when done. Through these the wire can be stretched, or the holes may receive long wire staples which clinch at the back of the post. These staples can be replaced at any time.

Another method consists of a tie wire passed around the post and then twisted tightly around the longitudinal fence wire, grooves or corrugations being made across the face of the post at the proper spaces for the wires. That is to say, the fence wires are secured into these grooves by passing a wire around the back of the post and twisting it.

A variation of the above method consists in using one continuous binding wire instead of a number of short pieces. The advantage of this and the above method is that the position of the ties does not have to be determined in advance (unless it is desired to make grooves or corrugations on the face of the pile), but may be readily shifted to suit any position of the fence wires.

In another method, holes are made in the concrete into which wires are inserted. These wires are then carried to the front of the post and wrapped tightly around the longitudinal fence wire.

Still another method is to take a No. 12 wire and with wire pincers bend loops into the wire extending out from the line of the wire about 1½ in., these loops being properly placed to receive the fence wire. When the form is filled within an inch of the top this wire is placed along the middle of the face, with loops extending past the surface of the face about ½ in. This is then built in with the last inch of the concrete.

A variation of the above method consists in using long staples or heavy bent wires well embedded in the concrete, being twisted or bent at the end to prevent extraction. These staples must be proper spaced to receive the fence wire.

Galvanized metal should be used for fasteners, since they are not protected by the concrete. A piece of small flexible wire, about 2 in. in length, threading the staple or bent wire and twisted several times with a pair of pliers, will hold the longitudinal fence wire in position.

Where it is desired to spike or nail to a post, a nailing block or strip should be bolted to the post.

Bracing Fence Posts.—In all wire fences considerable tension must be put on the longitudinal wires if a satisfactory fence is to result. To resist this tension occasional fence posts should be braced, and in no case must this bracing be omitted at the corner posts, and the post in many cases should be made heavier than the posts in the rest of the fence.

Art. 57. Concrete Railroad Ties

There are now innumerable designs and patents for the application of concrete, plain or reinforced, to the manufacture of cross-ties for railroad use.

Concrete Materials.—The cement should comply with the Standard Specifications for Portland cement of the American Society for Testing Materials, adopted June, 1904, together with subsequent changes and amendments. (See also Art. 4, page 43.)

The sand, gravel or broken stone, and water for concrete should conform to the requirements stated in Arts. 8, 9, 10 and 12. It is

usually specified that no gravel or broken stone greater than ¾ in. in diameter shall be used. The inspector will, of course, be governed by the specification requirement as to the size of aggregate.

Proportioning Concrete.—The concrete should consist of 1 part of Portland cement to 2 parts of sand to 3 parts of broken stone or gravel.

Molds for Concrete Ties.—A very rigid mold is required to form the ties. These may be made of heavy timbers or formed of metal molds. Great care must be taken in preparing the molds in order to cast the ties to accurate dimensions and leave the holes exactly in the right place for the spiking device. The interior facing of the mold should be covered with a proper lubricant before casting each tie.

Reinforcing Concrete Ties.—The reinforcement must be accurately placed as shown on drawings. It must be set parallel to the axis of the mold. The best practice is to assemble and wire the reinforcement into unit frames for placing.

Concreting Ties.—Great care in tamping or puddling is necessary to insure the corners of the mold being well filled, and if this detail is not carefully watched, the reinforcement, being exposed in places, will be subject to rust. The concrete must be thoroughly compacted.

Curing Ties.—After casting, the ties should be given plenty of time to harden before they are disturbed in any way. They should be thoroughly sprinkled at least twice a day for the first week after making, and as often thereafter as may be considered necessary. They should be allowed to harden for 2 months before being placed in the track. (See pages 335 and 538.)

Cushion Blocks.—The cushion blocks may be oak, birch, beech, maple, southern pine, or other close-grained hardwood. They should be cut from green or living timber, being perfectly sound and free from check or shake. After being thoroughly seasoned, they should be creosoted until they are thoroughly impregnated to a depth of at least ½ in. from the surface.

Art. 58. Concrete Sewer Pipe

Sewer pipes may be constructed of concrete, plain or reinforced by longitudinal straps and transverse bands, expanded metal or other approved reinforcing material. When properly joined together, with the connecting joint or seam thoroughly cemented, it should form one continuous piece of pipe.

There are good and bad grades of concrete pipe, and the pipe must be properly made and used, or the results will prove unsatisfactory. The possibility of weak and porous spots in concrete pipe is probably the greatest fault. One shovelful of gravel deficient in or poorly mixed with cement makes a defect in the pipe line which cannot be remedied. Where the concrete layer is as thin as it must be in a pipe to compare with a vitrified clay pipe, the danger is, of course, greater than with concrete in thicker layers.

Not for a moment even must the vigilance of the inspector or the faithfulness of the workmen be relaxed if good pipe are to be obtained. Even under these conditions, some imperfections are likely to be found in the pipe.

MANUFACTURE

All materials used in the manufacture, the process of manufacture, and the marking and dating of pipe should be subject to inspection at the factory.

Methods of molding, trimming and seasoning pipe should be left to the discretion of the manufacturer.

Marking and Dating.—All pipe should have the factory and manufacturer's name clearly impressed on the outer surface as identification mark, and should in like manner have the date of the molding of the pipe indicated.

Dimensions.—Pipes not intended for curves or bends should be true and straight. Each straight pipe having a branch or connection molded thereon should not be less than 2 ft. or more than 3 ft. long; plain pipe should be in length not shorter than 2 ft. nor longer than 3 ft.

The hubs of all pipe should be of the self-centering type, and there should be left an annular space to permit of the making of a layer of cement mortar at least $\frac{1}{8}$ in. in thickness between the hub and spigot.

Concrete Materials.—The concrete should be made of the best grade of Portland cement and good clean gravel or broken stone, free from earth, loam or other foreign or injurious matter, and good clean quartz sand, free from any and all earth, dust, loam or clay material. The gravel or broken stone should be of graded sizes, in which there should be no piece larger than $\frac{1}{2}$ in. in any direction for pipe up to 24 in. in diameter, and 1 in. in any direction for pipe 30 in. and larger in diameter. (See Arts. 8, 9, 10 and 12.)

All gravel used should be quartz or granitic gravel. Broken stone, if used, should be trap or igneous rock, containing no efflorescing, deteriorating substance, and sharp and angular in cleavage. Furnace slag of the above dimensions is sometimes used.

Proportioning Concrete.—Pipes 12 in. and under in diameter should be made of 1 part Portland cement to $2\frac{1}{2}$ parts of clean sand. Pipes 15 in. to 24 in. in diameter should be made of 1 part Portland cement to 1 part sand to 2 parts of hard stone. Concrete in the proportion of 1 part Portland cement to 5 parts of sandy gravel as taken from the pit is sometimes used.

Mixing Concrete.—The concrete may be mixed either by hand or with a suitable batch mixer (see Art. 15). It should be mixed in batches large enough to make at least one complete section of pipe. Sufficient water should be used to make a "wet mix."

Molds for Sewer Pipe.—Molds may be of steel, or wood covered with steel. They should preferably consist of cast iron bottom rings and sheet steel inner and outer casings, which should be rolled to a

true circle for the size for which they are intended, and the two casings should be concentric when the mold is assembled. The spigot should be formed by cast iron top rings.

The molds should have no longitudinal cracks extending through the inner or outer casings which will allow the water from the concrete to run through. They should be truly concentric and regular in form, and the shells or casings should be so connected as to remain the correct distance apart during the entire operation of filling, and should be so constructed and maintained as to give a pipe of uniform, even and equal distance at all points. It cannot be too strongly insisted upon that the molds be rigidly held in position so that they cannot be distorted while the concrete is being placed in them.

Reinforcing Sewer Pipe.—Special and adequate provision should be made to insure that the reinforcement is placed and held properly in the mold in all directions, so that no displacement, distortion, bending, buckling, breaking, or any other derangement or injury will occur during the placing of the concrete in the molds. The reinforcement must be held rigidly in position, so that it will be uniform in all sections.

Concreting Sewer Pipe.—Each and every batch of concrete should be sufficiently large to make at least one full pipe, and no pipe should be accepted or permitted to be placed in the trench which has not been constructed from commencement to completion in one single operation without appreciable break or cessation of labor in the whole operation of making pipe. No residue or remainder of concrete left after making of any pipe should be used in the making of any other pipe, unless the residue or remainder shall be used immediately in the making of such other pipe.

The concrete should be placed into the molds as quickly as possible after mixing, and should be deposited in thin layers and thoroughly tamped or puddled with a suitable slice-bar. In no case should retempered concrete or concrete which has had its initial set be used.

Protection of Pipes (Curing, Etc.).—The pipes should be protected from the sun during construction, and kept in a moist condition by means of frequent sprinkling and the application of bags or sacks saturated with water, for a period of at least one week after the removal of the forms.

The time of the first sprinkling and the frequency of sprinkling thereafter depend entirely upon the weather conditions. During a hot, dry season in summer pipes need to be wet down as soon as two hours after being taken from the form; after that they will require sprinkling two or three times a day. The pipes should never be allowed to dry for the first week. At the end of this time they should be allowed to remain in the sheds for a day or two, protected at all times from drafts. (See pages 335 and 538.)

Special precautions must be taken to insure against injury or damage to the pipes, both during and after construction, from freezing or other ill effects resulting from low temperature (see Art. 33). All ingredients entering into construction should be properly and

thoroughly heated, and the pipe during and after construction should be kept and stored in warm and tight rooms or sheds.

At all times, the pipes must be thoroughly cured before being brought into the exterior atmosphere. The complete process of curing should not occupy less than 30 days.

Openings for Connections.—Openings for bevel or other connections should be left and so as not to interfere with the strength of the pipe, and so as to permit of connections being easily and quickly made, and to give a smooth, even and tight joint. Such openings should be of a form permitting the connection to enter without cutting or chipping pipe in order to introduce the connecting pipe.

Character or Finish of Pipes.—Pipes should be without warps, cracks, or imperfections. The inside surface of the pipe should be smooth and true, and no pipe should be patched with cement or otherwise. Pipes should be rejected which are not of good, sound and dense material throughout, or which show the use of poor materials or imperfect mixing or compacting.

No longitudinal or transverse seams extending through the shell in a straight line should be permitted. Pipes showing the formation of seams, lines or areas of unhomogeneous or non-uniform concrete should be immediately rejected and not permitted on the line of the work.

No pipe should be used which has a piece broken from the spigot end deeper than the depth of the bell or longer at any point than one-half the diameter of the pipe, nor which has a piece broken from the bell end if the fracture extends into the body of the pipe or is longer at any point than one-half the diameter of the pipe.

All pipe and specials which are designed to be straight should not exhibit any material deviation from a straight line. Special curves or bends should substantially conform to the degree of curvature and general dimensions that may be required.

TESTS

Pipes may be subjected to the following tests:

External Crushing Test.—When supported upon a bed of thoroughly compacted sand of such dimensions and in such manner that an even bearing is provided throughout the whole length, but without appreciable displacement of the sand at the sides, the various sizes of pipe should withstand the following pressures applied at the crown uniformly along a line 1 in. in width and extending the whole length of the pipe, exclusive of the bell:

Diameter	Pounds per linear foot	Diameter	Pounds per linear foot
6	1,000	15	1,300
8	1,000	18	1,450
9	1,050	20	1,600
10	1,100	22	1,800
12	1,150	24	2,000

Drop Weight Test.—Pipe supported on a dry sand bed 2 in. deep should withstand, without cracking, the impact from two blows of a cast iron ball, weight from 8 to 10 lbs., falling 18 in. This test may be applied on the line of the work before the pipe is placed in the trench.

Hydrostatic Test.—Untreated pipe should show no percolation up to 10 lbs. per square inch, and should resist fracture at 35 lbs. per square inch internal pressure.

Quality or Fracture of Pipe.—When any pipe is broken it should appear homogeneous throughout, being entirely free from cracks or voids, and generally uniform, showing pieces of fractured stone firmly embedded in the mortar, where stone enters into the composition.

LAYING

No pipe should be laid except in the presence of an inspector, and the engineer may order the removal and relaying of any pipe not so laid. Previous to being lowered into the trench, each pipe should be carefully inspected, and those not meeting the requirements stated above should be rejected and either destroyed or removed from the work.

All lumps or excrescences on the ends of each pipe should be removed before it is lowered into the trench.

No sewers should be laid within 10 ft. of the excavating or 40 ft. of the blasting.

Method of Laying Pipe.—The pipes and specials should be so laid in the trench that after the sewer is completed the interior surface thereof shall accurately conform to the grades and alignment fixed and given by the engineer. All adjustment to line and grade of pipes laid directly upon the bottom should be done by scraping away or filling in the earth under the body of the pipe, and not by blocking or wedging up.

The sections should be laid with the spigot ends toward the outlet. The ends of the pipe should abut against each other in such a manner that there shall be no shoulder or unevenness of any kind along the inside of the bottom half of the sewer.

Special care must be taken to insure that the pipes are well bedded on a solid foundation.

Pipes having any defects which do not cause their rejection should be so laid as to bring these in the top half of the sewer, and if the bell or spigot be broken the defective place should be liberally covered with neat cement mortar, reinforced with a pipe or pipe ring, if so desired.

Before laying, the interior of the bell should be wiped smooth, and the hub and spigot thoroughly wet, and the annular space should be free from dirt, stones and water.

No length of pipe should be laid until the preceding length has been thoroughly embedded and secured in place, so as to prevent any movement or disturbance of the finished joint.

Joints: How Made.—The mortar used for making joints may be composed of 1 part Portland cement to 1 part of sand.

In making joints between concrete pipe, the space or gap between the ends of the section should be thoroughly wetted just before the joint is made.

The joint may be made of a thick grout in the proportions stated above, being poured around and into the gap until no more will enter. A special band is sometimes used on the interior of the sewer while the grout is being poured and until the same has completely set.

Instead of using grout and pouring it into the gap, mortar may be laid in the collar in such a manner that when the spigot end is driven into the collar the mortar will find the annular space between the spigot and the limbs. Special care must be taken properly to fill with mortar the annular space at the bottom and sides as well as at the top of the joints. After such space has been filled, the mortar having been compacted with a wooden or iron calking tool, a neat finish should be given to the joints by the further application of a similar mortar to the face of the hub, so as to form a continuous and evenly beveled surface from the exterior of the hub to the exterior of the spigot all around. A long, thin, flexible rod may be run into all joints to insure their complete filling.

Joints must be smoothly pointed-up on the inside of the sewer or drain, mortar being wiped around the inside of the joint in order to fill any vacancies which may be left.

All joints must be water-tight.

Cleaning Pipe.—The interior of the joint should be wiped clean of cement by a wad made of a sack filled with hay, large enough tightly to fill the pipe, and attached to a rod or cord, which should at all times be kept in the sewer and pulled ahead past each joint as soon as cemented.

Filling around Joints.—As soon as the cementing of any joint has been completed the bell-hole under the hub should carefully and compactly be filled with sand, loam or fine earth, so as to hold the exterior mortar finish of the joint securely in its place.

Water to Be Kept Out.—The trenches where pipe-laying is in progress should be kept dry, and no pipe should be laid in water or upon a wet bed, except when especially allowed by the engineer.

All water must be kept out of the bell-hole during the laying, or else such bell-hole should be completely filled with cement mortar in the proportions specified above or with concrete.

As the pipes are laid throughout the work they should be protected from dirt and water, no water being allowed to flow in any of them in any case during construction, except such as may be permitted by the engineer.

Alignment of Pipe.—While the pipes and specials are being laid in each section between manholes or other permanent openings, light from the remote end of the section should remain constantly in plain view throughout the entire length of such section or division.

No Walking on Pipes.—No walking on or working over the pipes after they are laid (except as may be necessary in tamping the earth

and refilling) should be allowed until there are at least twenty-four (24) inches of earth over them.

Protection of Pipe Ends.—In all cases the mouth of the pipe should be provided with a board or other stopper, carefully fitted to the pipe, to prevent all earth and other substances from washing in. In rock excavation the mouth of the pipe should be carefully protected from all blasts.

CHAPTER XI

INSPECTION OF MOLDING AND DRIVING CONCRETE PILES

There are two general methods of concrete pile construction: (1) those where a hole is made in the ground, into which concrete is rammed and left to harden; and (2) those molded or rolled in advance, allowing the concrete to set, and afterwards driven by methods similar to those used for driving timber piles, i. e., with a hammer or some other means.

For brevity, the above types or classes of concrete piles will be designated (1) Cast-in-Place Piles, and (2) Cast-and-Driven Piles.

Concrete piles can, in general, be used under almost all conditions in which timber piles are employed, and in many situations where the latter would be impracticable. Concrete is also employed to protect from decay, or from the ravages of the teredo, timber piles already in service. With the use of concrete piles there is a great saving in excavation, as these piles can be "cut off" at any grade, whereas timber piles are cut off at mean tide, and therefore necessitate considerable excavation, and sometimes loss of time on account of the tide rising above the work.

Concrete piles should be larger in diameter and generally fewer in number than timber piles for the same structure, being spaced to carry from 25 to 30 tons. The loads allowed on concrete piles will depend upon the nature of the ground and the system used, but should not exceed 40 tons, as a rule. Concrete piles of about 16 in. in diameter have been tested to carry 65 to 75 tons.

Art. 59. Cast-in-Place Piles

Piles of the "cast-in-place" type are made by forming a hole in the ground and filling it with concrete. Piles constructed in this manner may be either plain or reinforced, depending largely upon the character of the work for which they are to be used. These piles are usually without reinforcement.

Methods of Molding Piles in Place.—Various methods are employed for molding piles in place, being usually controlled by patents, and pile construction by these methods is done only by certain firms. The pile hole is made artificially and afterwards filled with concrete. This may be done by driving a wooden pile, or dummy, of the proper length and withdrawing it, the hole left being at once filled with concrete; or it may be made by driving a steel tube with a removable driving point and filling the hole with concrete as this tube is drawn

up, the concrete settling and filling the space occupied by the tube or shell; or it may be made by driving a collapsible steel core, encased in a closely fitting steel metal shell, the core being withdrawn and the shell filled with concrete.

The first method may be used in certain kinds of soil, such as stiff clay, the wooden pile or dummy being driven to the proper depth and withdrawn, the hole left being at once filled with concrete. The application of this crude method is somewhat limited, as it is seldom that the soil will stand until the hole is filled with concrete.

In the second method the pile is driven as follows: A steel shell, any diameter and of sufficient thickness to withstand fall of hammer and pressure of soil in driving, is fitted with a removable driving point, usually a cast iron shoe. After the steel tube or shell is "down" the hammer line is hooked to a concrete bucket and the shell is filled with concrete, usually a $1:2\frac{1}{2}:5$ mixture. The tube is then withdrawn, and as it is pulled from the ground the concrete settles and fills the space occupied by the tube. These piles have been driven as close as 3 ft. on centers.

In the third method, which is similar to that just described, some form of collapsible steel core, encased in a closely fitting shell of suitable material, is driven in the usual manner to the desired penetration, the core withdrawn, and the shell filled with concrete.

Another form of pile, which is really a column with an enlarged footing, has also been used. In one sense of the word this is not a true pile, and for this reason was not mentioned above. A shell of the diameter desired is made up in short sections and driven, and the material is excavated by a laborer and removed by means of a small bucket and hoist. As the excavation lowers, additional sections of shell are bolted on and the whole driven down until the desired penetration in solid ground is reached. If the material is self-sustaining the radius of excavation is increased as it lowers until the desired area is obtained, and a reinforced concrete footing is constructed up to the shell, and the shell then filled with concrete to the desired grade.

Inspection of Cast-in-Place Piles.—The chief uncertainties with piles molded in place are whether the concrete is properly placed and tamped and remains uninjured until it has hardened and gained its strength. These uncertain points should be carefully watched out for by the inspector. The following rules should also be observed for concrete piles in place:

Pile-Core Method.—The core should be so constructed that when the desired depth has been reached it will collapse and loose contact with the shell. It should be easily withdrawn, leaving the shell or casing in the ground, to act as a mold or form for the concrete. The shell should be made of material heavy enough to withstand the side pressure of soft ground or the shearing effect of boulders or gravel.

Driving Piles in Place.—The core and shell should be driven into the ground by means of a pile driver. In driving the shell or core for new piles, care must be taken that adjacent piles in which the

concrete is still green are not jarred and injured, as the jar in driving is sometimes considerable in certain kinds of ground and may easily endanger the setting and hardening of adjacent concrete work. In other words, be absolutely certain that freshly deposited or unset concrete is not disturbed by driving for other piles in the vicinity, in such a way as perceptibly to compress and move the earth.

Proportion of Concrete for Piles.—The concrete used in making piles should be of the best quality of Portland cement, complying with the Standard Specifications of the American Society for Testing Materials, mixed in the proportions of 1 part cement, 2 parts of sand and 4 parts of broken stone or gravel not larger than 1 in. in size. A strong, dense concrete is required for piles, and the usual precautions for securing it should be observed.

Reinforcing Piles in Place.—The reinforcement should be assembled into a unit frame and placed parallel to and concentric with the axis of the pile.

Concreting Piles in Place.—The concrete should be deposited with care to prevent segregation of stone from mortar and to prevent admixture of dirt with the concrete, being thoroughly tamped during the filling process, so as to insure filling of the hole. The concrete must be solidly compacted so that piles will have sections without voids of any kind.

Cutting Piles to Proper Height.—After the piles have been driven and the concrete is set the tops of same should be leveled off to the proper height to receive the footing bearings as may be directed by the engineer. This to include the cutting away of all shells or trimming off the top of the piles as may be required to bring same to proper level.

Art. 60. Cast-and-Driven Piles

Piles of the "cast-and-driven" type are first cast in some convenient locality and when thoroughly seasoned are transported to the desired site and driven. These piles are made of reinforced concrete, molded to the desired shape and cured before being driven.

Difficulties in driving have been experienced in some soils, but by the use of improved methods it is now possible to drive them in almost any soil that timber piles will penetrate.

Reinforcement.—All piles of the "cast-and-driven" type must be reinforced with sufficient steel properly placed in order to prevent any injury to the pile as it is raised from the ground to position between the leads of the driver, and to withstand the strains to which it may be subjected in driving. The pile is hoisted and handled by a line from the pile driver which is fastened at or near the butt, and consequently the pile has to sustain its own dead weight by being raised, as well as shocks and impact against obstacles, before reaching its position in the leads of the pile driver.

Piles of this type are usually reinforced both with longitudinal rods and hooping, the reinforcement consisting of one or more rods or shapes placed either on the axis of the pile or near its perimeter.

The reinforcement may be any of the forms used for reinforced concrete columns.

In general, only sufficient sectional area of material should be put in the reinforcement to take the tensile stresses caused by the bending action when handling the pile preparatory to driving. With the point on the ground and the other end being elevated, the pile should act and be designed as a beam supporting its own dead weight and shocks. More reinforcement than this is only necessary when the piles are used for piers, wharves, etc., where a considerable length of pile is not supported sidewise, or where they are subjected to bending stresses, which would obtain if the piles were used in connection with ferry slips or landings.

Methods of Driving Cast Piles.—Piles of the "cast-and-driven" type may be driven with a drop-hammer or a water-jet. In the former case, the pile is cast in a form, reinforced with rods and wire, and provided with a cast iron point. The pile is then driven in the same manner as a wooden pile, after being allowed to season properly, using a false or cushioned head of some easily compressible material to prevent excessive shocks to the pile.

If the pile is to be sunk by a water-jet, either an iron pipe is set in the center of the concrete or a hole is molded in the longitudinal center of the pile, the core being about 4 in. in diameter at the top and 2 in. at the bottom. Through this core the water-jet is inserted for sinking the piles into place. With the aid of the water-jet and light blows of a hammer, or even the weight of the hammer in some soils, the desired penetration may be obtained.

One contractor makes longitudinal grooves on the exterior surface of his piles, thus allowing the water from the jet to escape as the pile is being driven. This fluting increases the superficial area of the pile, thus increasing the skin friction.

Local Conditions.—All of the items entering into the manufacture and placing of cast-and-driven piles should be varied to suit the local conditions. As far as practicable the length of these piles should be known before they are driven, as it is not practicable to splice them, and it is difficult and expensive to cut them. Penetration should be determined before the piles are brought to the site, for the piles may be either too short or too long.

Inspection of Cast-and-Driven Piles.—The chief uncertainty with cast piles is whether the piles after driving are still sound or have been injured by the driving. This uncertain point should be carefully watched out for by the inspector. The following rules should also be observed for concrete piles that are cast-and-driven.

MOLDING PILES FOR DRIVING

Piles for driving may be molded like columns in vertical forms (see page 306) or like beams in horizontal forms (see page 311). Both methods of molding are used in this country, while horizontal molding seems to be the custom in Europe. The choice of the

method of molding cannot be decided off-hand, as excellent piles have been produced by both methods.

Piles should be cast upright if made of dry concrete, so that the joint between the layers or laminations will be normal to the direction of the driving. With wet concrete it is not important whether the piles are cast vertical or horizontal. A consideration of the following principles will be useful in determining whether to cast piles vertical or horizontal.

Any laminations are perpendicular to the load when molded in the vertical position, thus resisting shocks due to the action of the pile-driving hammer in a much better manner. Considerable difficulty is met with in molding piles vertically, due to the small space in which the concrete must be deposited and tamped. However, vertical piles may be constructed near each other and held in a rack or frame, thus reducing the area of the construction and storage yard.

The process can be inspected better when molded in a horizontal position. Horizontal molding may be used in the construction of sheet piling, as in many cases the principal stress acts transversely to the axis of the pile.

Molding Bed.—The procedure in constructing "cast-and-driven" piles commences with the preparation of the platform or molding bed upon which the piles are cast and cured. This will vary with the site, but it is desirable to select a flat and convenient location near the place of driving. It is very important that the platform shall be a rigid plane, in order that the piles may not become distorted during setting. That is to say, the platform must be stable, so that settlement due to the weight of the piles is avoided.

Where the ground is soft and yielding, ordinary pine stakes 2 by 4 in. by 3 ft. long, pointed at the ends, may be driven to a solid bearing. These stakes should be located at intervals of about 4 ft. in each direction and the tops cut to a uniform level. The 4x4-in. pine sills should be toe-nailed to the top of the stakes in longitudinal rows about 4 ft. on centers. Upon these sills a 2-in. solid wooden floor may be placed, which forms the molding bed. It is desirable that this bed shall be uniformly level to receive the forms for the piles.

Forms for Cast Piles.—Forms should be so made that they may readily be detached and used again. The number of forms required will vary with the quantity of piles to be made and the prospective salvage in the lumber.

Forms should be straight and kept true to line and level. Surface roughness, joint marks, etc., are not objectionable, but a pile which is not straight is liable to fracture in driving or under load. The forms for the piles should be water-tight.

Each concrete pile should be cast in a separate and distinct form, of sufficient stiffness to hold the concrete absolutely true to shape. Piles may be cast in a square form made of two pieces of 2x8-in. dressed pine battened together and placed on edge to form the sides

of the pile. The bevels or angles for tapered or octagonal piles may be made by placing loose pieces of beveled wooden strips at each corner of the form.

All forms should be thoroughly cleaned after each casting, and should be thoroughly coated with crude oil or other approved lubricant each time the forms are used. (See page 239.)

Care must be taken to see that the forms are supported by a rigid foundation or molding bed, as mentioned above.

Reinforcing Cast Piles.—The reinforcement should be accurately spaced and located as called for on the plans, and proper and approved means should be taken to insure against movement of the reinforcing rods after having been properly placed.

The reinforcement should be assembled or made into units, so that it can be placed in the forms at once. In other words, the entire reinforcement for one pile should be assembled and wired before it is put into the form. The reinforcement should be set parallel to and concentric with the axis of the mold, and kept rigidly in this position during concreting. If there are any kinks in the reinforcement, a few staples or nails driven around the rods into the molds will straighten them. Be sure that the reinforcement is concentric with the mold.

At the top one of the main reinforcing rods may be bent to form a ring to facilitate handling the piles, provided that this provision has been made in fabrication of the rods for the piles.

Cast Iron Shoe.—The piles should be provided with a cast iron shoe at the bottom, or a steel plate covering to protect the point and to facilitate penetration.

Proportioning Concrete for Cast Piles.—The concrete should be mixed in the proportions of 1 part Portland cement, 2 parts sand, and 4 parts broken stone or gravel. The broken stone or gravel should pass a $1\frac{1}{4}$-in. ring and be retained on a $\frac{1}{4}$-in. screen.

Concreting Cast Piles.—When a reinforcing unit is suspended and centered in position, the concrete of a wet consistency should be deposited and carefully puddled. The concrete should be thoroughly worked around all reinforcing rods and throughout the entire mass of the pile, by puddling or other approved method, until the concrete is thoroughly compact.

Each pile should be made one continuous operation from the first placing of concrete in the form until the pile is finished, without interruptions, in order that the most perfect bond may be secured. In other words, when any one pile is started it should be carried through to completion without interruption, so as to avoid all lines of cleavage that might result in a weak spot in the pile.

The concrete should be poured at several points along the form to prevent flowing and segregation. Do not depend upon filling the form by pouring at one place, as the concrete will be in uneven streaks.

At times while the molding of the pile is in progress, the central core, if provided with one, should be given a partial turn to prevent

the setting of the cement holding it fast and thereby preventing its final removal.

Casting Piles in Tiers.—Independent supports should be provided for each tier of molds in casting piles in tiers. At least one side of the form should preferably be in short sections that may be put in place as needed, in order to facilitate placing the concrete. The forms should be set up vertically with the longitudinal reinforcing rods in position. Enough concrete should be put in the forms to fill 10 to 18 in. in length, after which a set of transverse tie rods or wires should be placed, then another layer of concrete, etc. The concrete should be mixed rather wet, as thorough tamping is difficult in the confined space. For methods of concreting columns, see Art. 25, page 306.

Removal of Forms.—As soon as the concrete of the pile has solidified—that is, after the pile has been allowed to set a sufficient length of time to retain its shape—the forms may be stripped and used for making other piles. The pile form should remain in place at least 24 hours, and as much longer as may be necessary. No special care is necessary in taking off forms.

Curing Piles.—The concrete piles should be properly protected from the direct rays of the sun, and should be kept damp by proper covering and sprinkling for at least one week after casting, being allowed to set for a day after molding, without water. They should then be sprinkled every day for about a week, when they may be removed from the molding bed or platform, and, if possible, set in a vertical position; or they may be laid flat on the ground or stacked with others until required for the work.

Great care should be taken that there is a sufficient amount of moisture in the pile to permit of the proper action for the setting of the cement. This may be accomplished by covering the piles over with burlaps or a thin layer of hay and saturating with water from a hose. The pile must be sprinkled and kept in a damp condition for at least 7 days, being thoroughly wetted by hose three times a day, including Sundays and holidays.

Piles should be allowed to set at least 4 weeks before being driven, and as much longer as is possible.

The curing of concrete in the normal manner described above delays the driving of the piles for a period of not less than 28 days, although a greater length of time is usually desirable, especially in cold and damp weather. In order to avoid such a long delay, the piles may be cured by steam. This enables such piles to be made and driven within three or four days, and places the speed of driving on the same basis as that of the "cast-in-place" type described in Art. 59.

Precautions should be exercised in making sure that the concrete has solidified and that it has received its initial set before exposure to steam treatment.

Character or Finish of Cast Piles.—All finished piles should be sound, homogeneous, and of regular section, being absolutely true to form and general dimensions shown on plans. They must be free from

wind and all defects which will affect either the appearance or the strength of the finished work. In other words, cast piles should be straight and without cracks or deeply chipped surfaces. Generally speaking, the rougher the outside of the pile, the more friction and the more its supporting power.

None of the reinforcing metal should be exposed.

The metal points, if such are used, should be firmly attached.

Cored piles for sinking by water-jet should be open and unobstructed.

Fluting or corrugations, if such are used for water-jetting, should be unobstructed.

DRIVING CAST PILES

The excavation should be completed as far as possible before concrete piles are driven.

Great care is required in handling and driving concrete piles. The driving should be done in such a way that the pile is not fractured in the body. All piles should be driven plumb and absolutely true to line. Great care should be used to bring the top of the pile to the proper final elevation.

The methods of driving concrete piles are similar to those used in driving timber piles. They may be driven with an ordinary pile driver, using a heavy hammer and a short drop, a steam hammer being preferable; or they may be driven by means of a water-jet, which in most respects is a process similar to that of jetting wooden piles. This method of driving is advisable for all but short piles. A combination of the hammer and water-jet has been found to be the most successful manner of driving concrete piles.

Driving Piles with Hammer Driver.—Piles of the "cast-and-driven" type may be handled and driven by using pile drivers of the ordinary type, but equipped to handle the heavier concrete pile. That is to say, the plant required need not vary from that ordinarily used for driving timber piles, except that more power must be provided for handling the heavier concrete pile and that the pile driver frames and tackle must have sufficient strength to lift the extra weight. Means must also be provided for holding the concrete pile in line and protecting its head.

The weight of the hammer should generally be greatly increased and the height of the fall decreased, rather than using a light hammer dropping a greater distance. The blow of a light hammer will be absorbed locally and shatter the pile. The weight of the ordinary drop-hammer should be increased in the ratio of weight of hammer to weight of pile, or from 2 or 3 to 1, so that the weight of the drop-hammer for driving concrete piles will not vary from 7,000 to 12,000 lbs. The height of the drop should not exceed 8 or 10 ft.

The amount of penetration under the last blows of the hammer, the style and weight of hammer, etc., should be agreed upon by the contractor and the engineer before the work is started. The inspector should make his mind clear on these points and should see that the understanding between engineer and contractor is definite.

Care is required in hammer-driving. The pile must have become well cured and hardened and must be maintained exactly in line with the direction of the hammer blow, the alignment being perfect with the line of stroke of the hammer. A heavy hammer and a short drop must be employed. The pile must be protected by a special cap to cushion the hammer blow, in order to prevent shattering of the pile-head. This cushion cap is described in detail below.

Driving molded concrete piles with hammer drivers is an uncertain operation at best, and must be carefully watched by the inspector. It has been done successfully even in quite hard soils, and it can be done if time is taken and the proper care is exercised; but one is never sure that fractures do not exist in the portion of the pile underground and hidden. Shattered piles have frequently to be withdrawn. The driving of concrete piles must be watched carefully to discover cracks, excessive spalling, etc.

Compression or Cushion Cap.—The head of a concrete pile must be protected during driving, otherwise it will be shattered by the shock of the hammer. Special devices in the form of a drive-head or cap have been designed to act as a cushion on the head of the pile, being so arranged as to deaden the force of the hammer blow. A hollow, cast iron cap filled with sand or sawdust, and calked with clay and rope yarn, is sometimes used, fitting over the head of the pile like a helmet. The space between the lower end of the cap and the side of the pile is calked with clay and tow or other suitable material. Through a hole provided in the top of the cap, sand or sawdust is poured, the space between the pile and cap being completely filled. Such a compression or cushion cap effectually protects the pile-head, taking the direct blow of the hammer and distributing the pressure to the entire head.

Caps in the form of a sheet steel tube or collar, reinforced with steel rings filled with sawdust, surmounted by a wooden block or false pile, have been successfully used. The diameter of this cap is slightly larger than the head of the pile and is secured to it with hardwood wedges. The cap projects about two-thirds of its length above the head of the pile. Alternate layers of shavings and sawdust are placed in the cap or tube, which, when compressed, occupy about half the remaining space to the top, the purpose of the shavings being to reduce lateral thrust of the sawdust. A hardwood block or false pile, loosely fastened to the guides, is fitted into this collar. This false pile receives the shock of the hammer, the shock being distributed, by the shavings and sawdust, uniformly over the head of the pile. The cap sometimes consists of a cushion of confined sand, rope, or rubber hose, upon which rests a false pile, instead of the shavings and sawdust as mentioned above.

Again, a short timber false pile upon the head of the concrete pile may be used alone. Caps made of alternate layers of lead, wood and iron plates have also been successfully used.

Driving Piles with Water-Jet.—Concrete piles may be driven by jetting like timber piles, practically the same methods and apparatus being used. When it is the intention to drive piles with a water-jet,

the pile should preferably be cored or have a jet pipe cast in the concrete. In many cases it will be found necessary to use the pile driver in connection with the water-jet.

The method of driving piles by means of a water-jet is very simple, the jet being applied at or as near as possible to the point of the pile under a pressure of about 120 lbs. per square inch. The action of the water loosens the material around the point of the pile, thus rendering the soil more fluid, and the pile, either by its own weight or with very light blows from a pile driver, sinks into the loosened material. During the operation of driving, the water from the jet comes up on the outside of the pile and carries with it the material which it displaces during driving. This, with the blows from the hammer, forces the pile down, the process continuing until the pile reaches the desired depth and settles to a firm bearing. The skin friction is said to be increased when piles are driven by means of a water-jet beyond what usually exists when the pile is driven by a hammer alone, the action of the water puddling the earth firmly about the pile.

A special cast iron cap about 3 ft. in height, fitting over the head of the pile, is sometimes used. In one side of this cap is a slot from the outside to the center, which allows an opening for the projection of the jet water pipe. The cap is filled with rubber packing, and the top has a wooden block or false pile which receives the blow from the hammer, similar to the special cap described above. In this way the head of the pile is protected from injury during driving.

The efficiency of the water-jet depends to some extent upon the increased fluidity given to the material into which the piles are sunk, the actual displacement of material being small. Hence, the water-jet is most efficient in clear sand, quicksand, mud or soft clay. In gravel, or sand combined with gravel, or in hard clay, the water-jet is almost useless. For these reasons, arrangements should be made to deliver large quantities of water with a moderate force, rather than smaller quantities with high initial velocity. The efficiency of the water-jet may be increased by bringing the weight of the pontoon, on which the machinery is placed, to bear upon the pile by means of a block and tackle.

Jet vs. Hammer.—The choice between a water-jet and a hammer pile driver cannot be decided off-hand, as the conditions most favorable for each are directly opposite. Both are often advantageously used together, especially in hard, stiff clay. For inland work the hammer is usually preferable, owing to the difficulty of obtaining the large quantities of water necessary for the jet. For river and harbor work, on the other hand, the jet is the most advantageous. In sandy soils the jet is preferable, as the sand offers great resistance to driving with the hammer. In hard clay the hammer is much more expeditious.

Handling Cast Piles.—The method of handling cast piles to the driver should prevent damaging strains on the piles. All piles injured in handling or driving must be abandoned and new piles driven to the complete satisfaction of the engineer. Great care

should be exercised in the handling of the piles, and special equipment and tackle should be used for the purpose. Cast piles should not be dragged along the ground or otherwise roughly handled.

Cutting Piles to Proper Height.—It is sometimes found impossible to drive piles as deep as was anticipated, and they must be cut off to some grade to meet the footings. This may be done by using a heavy hammer and track chisel on the concrete, and a hack-saw on the reinforcement.

DEFINITIONS OF TERMS USED IN CONCRETE CONSTRUCTION

Like every other branch of human activity, the concrete industry has developed a list of terms of special meaning. With the usage of these terms, the more common of which are given below, the inspector of concrete construction should make himself thoroughly familiar.

Aggregates—The solid and relatively coarse ingredients, such as sand, broken stone, gravel, furnace slag, cinders, etc., which are bound together by the cement to form a mass of concrete. The term is sometimes erroneously applied to the coarse material, such as broken stone only. In the form of concrete known as "pulp concrete," sawdust, an organic material, is used as an aggregate.

Akron Cement—Natural cement from the vicinity of Akron, N. Y.

Argillaceous—Consisting of, or containing, clay.

Armored Concrete—See Reinforced Concrete.

Bag of Cement—Weighs 95 lbs. or is equivalent to one-fourth of a barrel of Portland cement or one-third of a barrel of natural cement.

Ballast—Broken stone or gravel used in making concrete.

Barrel of Cement—Weighs 380 lbs. for Portland, contains four bags of cement.

Batch—The definite quantity of concrete made at one mixing either by a gang of men or by a machine mixer. In hand mixing, ordinarily one barrel of cement and the proper proportions of sand and broken stone or gravel make a batch.

Béton—The French term for concrete.

Béton Armé—The French term for reinforced concrete.

Béton-Goignet—The French term for a mixture of hydraulic lime, cement and sand.

Blowing—Effect of air bubbles on finished surface, due to over wet mixtures not properly puddled or tamped.

Board Marks—The marks left by the forms.

Bonding—The uniting of one layer or course of concrete with another. (See Art. 27.)

Broken Stone—See *Crushed Stone.*

Bush-hammering—A method of dressing stone (applicable to concrete) with a hammer having large point-like teeth on the striking face.

Calcareous—Consisting of, or containing, calcium carbonate or carbonate of lime.

Calcining—Burning; subjecting to sufficient heat to cause partial chemical disintegration, or incipient or total fusion or vitrification.

Cement—The binding material which holds the aggregates together in concrete in a solid mass. Cement is a preparation of calcined clay and limestone or their equivalents, possessing the property of hardening into a solid mass when moistened with water. This prop-

erty it exercises under water, as well as in open air. Cements are divided into four classes; Portland, Natural, Puzzolan (or Puzzuolana) and Silica cements.

Centers—The temporary wooden or metal supports used in the erection of masonry arches or other superimposed or overlying constructive work—floor slabs, for example. (See also *Forms.*)

Centering—Same as centers.

Chats—Particles of hard gravel or crushed stone are known as "chats" in some parts of the country.

Checks—Same as hair cracks.

Cinder Concrete—Concrete in which cinders is used as one of the aggregates.

Concrete—An artificial stone made by mixing cement mortar with broken stone, gravel or other suitable material. The proportions of cement, sand and stone are generally expressed in parts by measure (occasionally by weight). A 1:2:4 (one, two, four) concrete means 1 part cement to 2 parts sand to 4 parts stone. A 1:3:5 concrete is made of 1 part cement, 3 parts sand and 5 parts stone (or gravel). When both stone and gravel are used, the concrete may be designated thus, 1:3:2:4, which means 1 part cement, 3 parts sand, 2 parts gravel and 4 parts stone.

Concrete Rubble—Masonry of large stones, usually of derrick size, with joints of concrete instead of mortar. (See also ***Rubble Concrete.***)

Concrete Steel—See ***Reinforced Concrete.***

Constancy of Volume—See *Soundness.*

Construction Joint—The seam between two successive day's work in concrete laying. (See Art. 26.)

Core—The mold used to form the hollowed-out part of a cement or concrete block.

Corrugated Bar—A form of reinforcing steel made by pressing the surface of a plain bar into a series of ridges or corrugations.

Craze—Same as hair cracks—generally the result of too rich a mixture—occasionally a sign of unsound cement.

Crazing—The checking or cracking of the surface of artificial stone, concrete, wearing surface of sidewalks, etc.

Crushed Stone—The terms *crushed stone* and ***broken stone*** are used indiscriminately to designate stone that has been broken by a rock crusher.

Crusher Run—Crushed stone or gravel taken directly from the crusher with none of the fine material, dust or "flour," screened out.

Density—Represents the ratio of the sum of the volumes or mass of the particles, or absolutely solid substance, of a material contained in a measured unit volume to the total measured unit volume.

Dressing—The finish given to the surface of concrete.

Dry Concrete—A mixture containing so small a percentage of water that very hard ramming is required to flush the water to the surface.

Efflorescence—The white or yellowish discoloration sometimes appearing on the surface of brick, concrete, stone, etc., due to the leaching out of soluble salts. (See Art. 31.)

Expanded Metal—A metal manufactured by cutting close parallel rows of gashes in steel sheets and then expanding the gashes laterally to form diamond-shaped openings.

Expansion Crack—Cracking in concrete work caused by expansion.

Expansion Joint—A vertical joint or opening between two masses of concrete to allow for variations due to changes of temperature.

Fabric, Wire—See *Wire Fabric.*

Facing—(1) A rich mortar placed on exposed surfaces to produce a smooth finish. (2) Shovel facing by working the mortar of concrete to the face.

Falsework—Wooden or other supports for holding concrete in position while setting.

Ferro-Concrete—See *Reinforced Concrete.*

Finishing—Working the concrete surface with steel trowels or similar tools, as for instance by brush, called brush finish.

Floating—Preparing the roughly spread mortar for the steel trowel by the use of a wooden or cork float. If this floating is used for a finish, it is called float-finish.

Flushing Concrete—Concrete is said to be flushed when water is brought to its surface by ramming or tamping.

Forms—Forms are the molds (usually of lumber) that hold the concrete in shape until it has set or hardened. There seems to be a misunderstanding as to the separation of forms and centers. Forms properly speaking consist of the timber work to form those members of concrete construction, such as columns, girders, etc., which must possess a certain regularity of form and evenness of outline. Centers, properly speaking, consist of timber supports for floor slabs, bridge centers, etc.

Frost Line—The average level to which frost penetrates into the ground.

Fusion—Melting; usually applied only to melting of mineral substances which takes place at relatively high temperatures.

Gauging—Determining the proportions of cement, sand, gravel or broken stone and water in concrete. Generally used in specifying the quantity of water that will produce a certain consistency.

Granolithic—Concrete consisting of Portland cement and fine broken stone or sand troweled to form a wearing surface; its most general use being as a top surface for concrete walks.

Grappiers Cement (*Ciment de grappiers*)—Made in France by grinding hard, under-burned particles which have escaped disintegration in the manufacture of hydraulic lime.

Gravel—Mixture of coarse, rounded pebbles and sand, or pebbles without sand.

Grout—A thin mortar composed of sand, cement and water; either poured or applied with a brush.

Hair Cracks—Fine hair-like cracks on the surface of a cement or concrete structure which has stood for some time.

Hardening—Commences after the final set of a cement mortar or concrete and continues for a number of years.

High Carbon Steel—A steel in which the elastic limit is not less than 50,000 lbs. per sq. in.

Hydraulic Cement—Any cement which sets or hardens under water.

Hydraulic Lime—Containing lime and clay in such proportions that it hardens under water.

Hydrated Lime—Specially prepared powdered slaked lime made by mixing quicklime and water. It can be bought commercially.

Laitance—The milky fluid, composed of particles of pier cement in water, which results when concrete is deposited in water or is mixed with an excess of water which arises to the surface of the concrete.

Laitier Cement (*Ciment de laitier*)—The French name for Puzzolan or slag cement.

Lean Mixture—A concrete containing a relatively small proportion of cement.

Lime of Teil (*Chaux du Teil*)—A celebrated hydraulic lime of France.

Limestone—An aggregate for concrete, consisting largely of CaO, CO_2 and SiO_2.

Loam—Earth or vegetable mold composed largely or entirely of organic matter.

Louisville Cement—A natural cement from the vicinity of Louisville, Ky.

Matrix—A term sometimes used to designate the body of cement and fine aggregate in which the coarse aggregates of cement are embraced.

"Mill Tailings"—The by-product of lead and zinc mines. It consists of crushed blue and white flint varying in size from $\frac{1}{8}$ to $\frac{3}{4}$ in. or over. "Tailings" or "Chats" or gravel, as it is commonly known, can be found in large piles at the mill and can usually be had for the hauling.

Mix—A shortened term for Mixture.

Mixer—A machine for mechanically mixing concrete.

Mixture or Mix—Refers either to the proportions of materials composing concrete or to its consistency.

Molds—See *Forms.*

Monolith—A term applied to single-piece work, or walls built with concrete between frames.

Monolithic—Built in one solid, continuous piece.

Mortar—A mixture of cement or lime and sand or other fine aggregate having water added so as to make it like a paste.

Natural Cement—Made from natural rock containing the required constituents in approximately uniform proportions. It may be further defined as a finely pulverized product resulting from the calcination of an argillaceous limestone at a temperature only sufficient to drive off the carbonic acid gas.

Neat Cement—Or cement paste, is cement mixed with water without the addition of any aggregate.

Parker's Cement—A term sometimes used in England for natural or Roman cement.

Paste—A mixture of neat, i. e., pure, cement or lime with water.

Plastic—Capable of being molded, formed, modeled, or spread, like mortar or paste.

Pointing—Filling in joints or depressions on the face of concrete.

Portland Cement—Made from an artificial mixture of materials containing lime and clay. It may be further defined as the finely pulverized product resulting from the calcination to incipient fusion of an intimate mixture of properly proportioned argillaceous and calcareous materials and to which no addition greater than 3 per cent has been made subsequent to calcination.

Puddling—The mechanical or hand stirring of wet concrete in the forms when too wet to be tamped or rammed.

Puzzolan Cement—An intimate mixture made by grinding together granulated furnace slag, or natural pozzolanas, such as volcanic ash, and slaked lime without further calcination, possessing the hydraulic qualities of cement.

Quaking Concrete—Concrete mixed with that proportion of water which will cause it to quake like jelly when heavily tamped.

Quick Setting—Term applied to cement which takes an initial set in a comparatively short time. The term is arbitrary.

Ramming—Heavy compacting of concrete with a suitable tool.

Regauging—Adding water to mortar which has become stiff and working same until plastic.

Reinforced Concrete—Variously known as armored concrete, concrete steel, steel concrete, etc., is concrete in which is embedded bars or wires of steel or iron in such form as to take up the tension and assist in resisting shear.

Reinforcement—The iron or steel used in reinforced concrete.

Reinforcing—Applying the reinforcement—also used in the same sense as reinforcement.

Retemper—To stir thoroughly again, so as to give workable consistency; to regauge, as in stirring up mortar or concrete that has already begun to set.

Rich Mixture—A concrete containing relatively a large proportion of cement.

Roman Cement—The English term for natural cement.

Rosendale Cement—A natural cement from the Rosendale District in eastern New York State.

Rubble Concrete—Concrete in which large rubble stones, or plums, are embedded. Stones from the size of a man's head to the size of a barrel are thus used. When larger stones are used, and the concrete becomes simply a coarse-grained mortar between them, probably the term *cyclopean masonry* is more correct than *rubble concrete;* still there is no distinct dividing line.

Sand—The term commonly applied to small particles of quartz; it is also used to designate small particles of stone such as crusher dust or very small gravel.

Sand Cement—Same as *Silica Cement.*

Scale—To flake off in thin layers.

Screenings—Applies to the product of the crusher (dust and chips) which passes through the smallest hole in the screen used to separate the broken stone into the different sizes. The size of the smallest screen varies from 1/8 in. to 3/4 in., so the word screenings has no definite meaning, although it can usually be taken to apply to all stone under 1/4 in. in diameter. In other words, it is the fine aggregate separated from crushed stone and used in the place of sand.

Setting—Setting refers to the process of chemical combination which takes place among the particles of cement when subjected to the action of water, resulting in its hardening.

Shrinkage Cracks—Due to contraction of concrete on account of temperature changes.

Silica Cement—A mechanical mixture of clean, fine sand and Portland cement.

Siliceous—Containing silica (quartz or sand), or partaking of its nature. Written also "Silicious."

Slag Cement—Another name for Puzzolan Cement.

Slam—A white scum forming on top of concrete laid with an excess of water.

Sloppy Concrete—Concrete mixed with that proportion of water which prevents it from being piled up in the barrow; it will run down a slightly inclined trough.

Slow Setting Cement—That which requires two hours or longer in setting. The term is arbitrary.

Soundness—Absence of tendency to cracking, swelling, shrinking, distortion, or disintegration under varying conditions of moisture and temperature; constancy of volume.

Steel-Concrete—See *Reinforced Concrete.*

Sylvester Wash—A waterproofing wash consisting of alum and soft soap applied alternately to the surface of concrete.

Tamp—To compact concrete firmly with a suitable tool, to reduce voids and force the aggregates as closely together as possible into a compact mass.

Twisted Steel Bars—Reinforcing material made by twisting square steel bars.

Underburned Cement—A cement burned at too low temperature; the clinker of such cement is lacking in density.

Vassy Cement (*Ciment de Vassy*)—A common French natural cement, obtained by heating limestone containing much clay at the lowest temperature that will decarbonate the lime; it sets very rapidly but hardens very slowly.

Voids—A term applied to the spaces between the grains of sand, or to the spaces between the fragments of gravel, crushed stone or other aggregate. The voids are expresses in a percentage of the total volume of the loose material. The term is also applied to the spaces throughout a mass of concrete, mortar, or paste that are filled with air or water.

Wearing Surface—Finished surface exposed to wear.

Wet Concrete—A mixture containing so much water as to require little or no ramming.

Wire Cloth—A term applied to a form of reinforcing fabric made of wires tied, crimped or welded at their intersections to form long strips of various dimensions. Such reinforcement is used for floors, roofs, and interior partitions, much as expanded metal is used.

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